Eastern European Reactor Safety and Management: A Preliminary Assessment

J. H. Bickel
N. O. Siu
T. J. Leahy
C. L. Smith

Safety and Risk Evaluation Unit
Idaho National Engineering Laboratory

1. Introduction and Summary

As the United States and other countries begin to offer assistance aimed at improving the safety of nuclear power plants in central and eastern Europe, it is imperative that an accurate assessment of the safety problems at these plants be developed. Recognizing that an effective safety culture goes far beyond the mechanical design and operational aspects of the plant, such an assessment must consider the less tangible aspects of safety such as management practices, employee motivation, effectiveness of training, procedural adequacy, control room team effectiveness, availability of resources, and a variety of related issues.

Funded by the United States Department of Energy, the Idaho National Engineering Laboratory (INEL) has completed a small project which is intended to demonstrate what lessons regarding Eastern European reactor safety can be drawn from different sources of readily available information. Based on the foregoing view that a safety culture must be evaluated from several different perspectives, this project has integrated published statistics and limited plant visits to arrive at a realistic understanding of nuclear safety for two selected plants.

This project has demonstrated that analysis of published operational data, combined with data of a more "anecdotal" nature, can yield valuable insights into nuclear safety in foreign countries. Employing the methods outlined in this report, the INEL found significant safety related differences between two nuclear power plant sites. Further, it was found that to a large extent, differences between the two plant sites which could be observed through direct inspection were also reflected in much of the published operational data. This finding suggests that to at least a limited extent, careful analysis of selected published operational statistics may provide a basis for assessing the safety of Eastern European nuclear power plants. A more complete picture emerges, however, by combining such analysis with plant visits, discussions with knowledgeable plant staff, and discussions with regulatory authorities in these countries.

It should be emphasized that the work accomplished on this project thus far represents more of a beginning than an end. The literature searches, evaluations of potential safety indicators, documentation of personal observations, and other work performed here is intended primarily to show the potential for developing and applying this work on a bigger scale. It will only be through the further development and application of the methods and insights presented in this report that an objective and comprehensive understanding of Eastern European reactor safety will emerge.

2. Preliminary Data Collection and Analysis

This chapter is divided into three sections. The first section discusses the basic characteristics of measures (or "indicators"[1]) that can be used to assess the current level of safety of a plant, and currently used or proposed indicators. This identification of appropriate indicators is useful in guiding subsequent data gathering and data evaluation efforts. The second section discusses sources of readily available information that can be used to evaluate the safety of Eastern European reactors. The third section performs an exploratory analysis of the data for two plants (the Jaslovské Bohunice Station in Trnava, Czechoslovakia and the Kozloduy Station in Kozloduy, Bulgaria) to determine the extent to which useful safety insights can be drawn from gathered information. It also shows that the statistical data available provide a picture of plant safety that can be interpreted in a manner consistent with anecdotal information (e.g., plant visit observations).

2.1 Indicators of Safety

Nuclear power plant accidents that affect public health and safety are, fortunately, rare events. However, the lack of countable events creates a problem for an assessor attempting to determine the level of safety[2] of a given plant: this safety level cannot be directly measured. As a result, the assessor must rely upon indirect indicators of safety, e.g., the annual number of events that potentially can trigger a severe accident scenario.

In the U.S., a large amount of safety indicator information is gathered and analyzed. This section describes the "performance indicators" and "systematic assessment of licensee performance" (SALP) ratings used by the USNRC in its evaluations of U.S. commercial nuclear plants, additional safety indicators proposed by USNRC-sponsored research, and facility-inspection guidelines employed by DOE which imply a set of indicators. The purpose of the discussion is to identify and evaluate specific indicators that could be useful in assessing the safety of a given East European reactor; the availability of information to support these indicators is discussed in Sections 2.2 and 2.3.

---

[1]It is important to note that the term "indicator" is used in this report in its most general sense, i.e., something that indicates. Thus, an indicator can be qualitative or quantitative. This usage is in contrast with the more specialized definition employed by NRC, among others, in which an indicator is a statistic.

[2]In this report, the term "safety" refers to public health and safety; occupational safety issues are considered only to the extent that they provide some insight into public health and safety issues.

To help in the evaluation process, it is useful to group the indicators according to some common characteristics. Ref. 1 presents a detailed framework useful for establishing relationships between a wide variety of performance indicators. A somewhat simpler classification scheme used in this work is based on the following indicator characteristics:

- Directness of relation to safety

  As discussed above, all indicators considered provide indirect measures of safety. However, some indicators are more directly related than others. For example, the number of reactor scrams per year is a more direct indicator than the size of a plant's maintenance budget. The latter may have a more pervasive effect, but is mediated by more processes. The advantage of a direct safety indicator is that the decision maker has less uncertainty in interpreting its significance. The disadvantage is that the indicator is often narrowly focused; fixing the cause of a high value for such an indicator may therefore not address a broad range of safety issues.

- Predictive power

  Many performance indicators assess how a given plant has performed (from a safety perspective) in the past. However, not all of these indicators provide reasonable predictions of future performance. "Leading indicators" are used to predict how a plant will perform in the future. They look at causal factors underlying plant performance. However, they often involve management and organizational factors and can be more indirectly related to safety than many historical indicators.

- Form

  Indicators can be qualitative or quantitative. (Numerical ratings of performance based on qualitative assessments are essentially qualitative indicators). Qualitative indicators (e.g., a "good" or "bad" rating for maintenance programs) are generally easier to develop, but can also have a more ambiguous relationship to quantitative measures of safety.

- Consistency

  Some indicators are subject to more reporting variability than others. A completely consistent indicator will be reported in the same manner, regardless of the body doing the reporting.

- Omissive power

  In some cases, a lack of information on a given indicator can provide an important indication concerning the willingness of an organization to report problems.

2.1.1 USNRC Programmatic Indicators

The USNRC uses a variety of information to assess the current status of commercial plants, and to determine which plants should be placed on a "watch list." Of particular interest to this project are two sets of formal indicators collected by the Office for Analysis and Evaluation of Operational Data (AEOD): the "performance indicators" (PIs) and the "systematic assessment of licensee performance" (SALP) ratings. Neither set is used exclusively to assess plant performance [2]. However, both sets provide important input to the rating process.

As described in Ref. 3, the official set of performance indicators consists of eight, largely self-explanatory, variables:

- automatic scrams while critical
- safety system actuations
- significant events
- safety system failures
- forced outage rate
- equipment forced outages per 1000 commercial critical hours
- collective radiation exposure
- cause codes

"Significant events" are events assessed by the NRC staff as having affected public health and safety, or as having significant potential to affect public health and safety; they are identified through a detailed screening and evaluation process. Significant events can, among other things, involve: degradation of important safety equipment, unexpected plant responses to transients, degradation of fuel integrity, reactor scrams with complications (e.g., personnel error), unplanned releases of radioactivity, operation outside the limits of plant technical specifications, and recurring events that indicate deficiencies in corrective actions, plant hardware, or administrative programs.

The "forced outage rate" is the number of hours associated with forced outages divided by the sum of hours the unit is in service (i.e., generator on-line hours) and forced outage hours.

"Cause codes" are assigned to each licensee event report, and are used to indicate potential problems in a number of areas. The following cause codes are used: administrative control problem, licensed operator problem, other personnel error, maintenance problem, design/installation/fabrication problem, and equipment failure.

Data for these indicators are collected for each plant and summarized in quarterly reports (e.g., [3]). Figure 2.1 shows a typical snapshot for a particular plant. Figure 2.2 shows an example of trending information provided in the quarterly reports. Additional details concerning the definitions of the indicators and their intended usage can also be found in these reports.

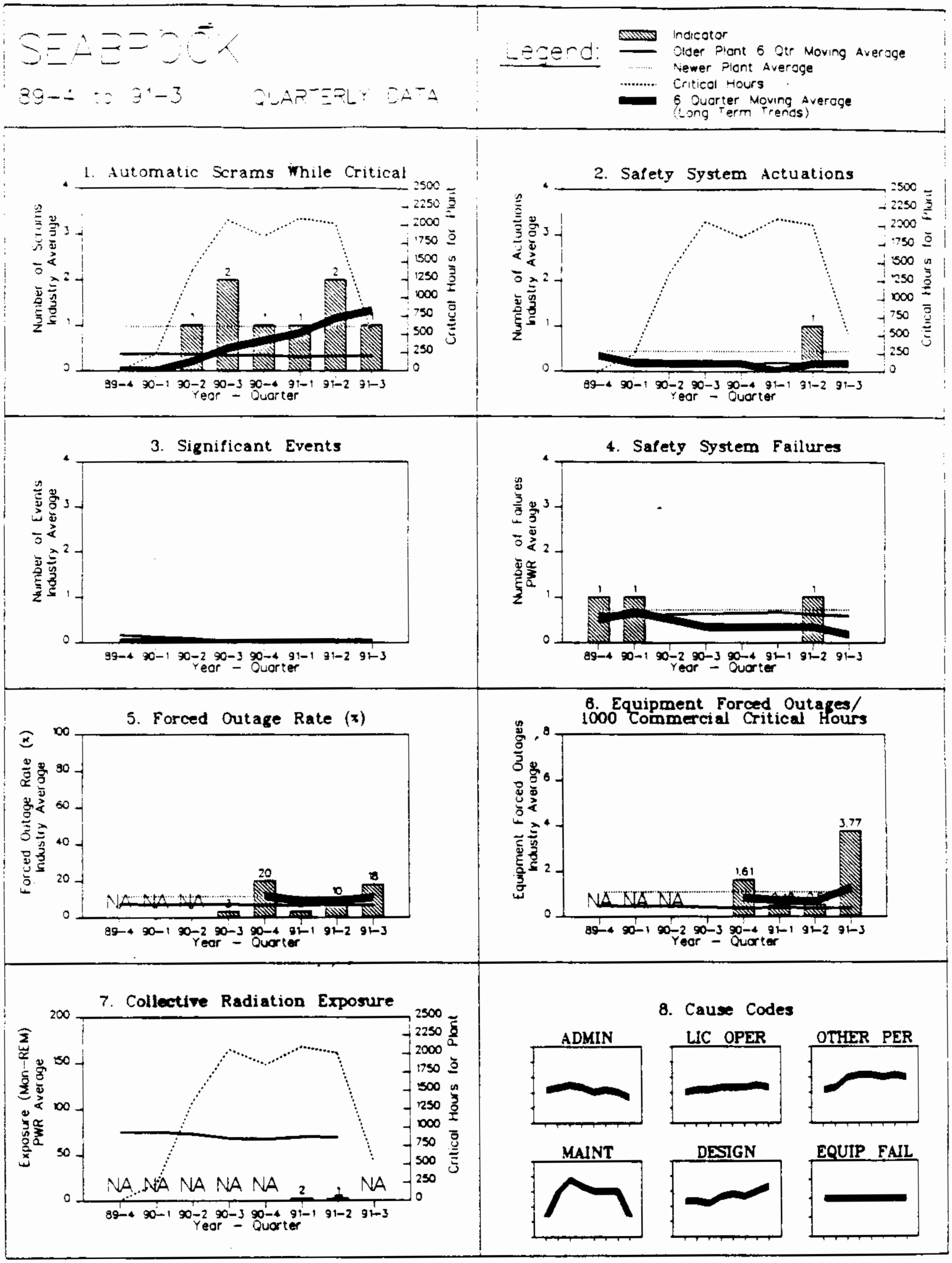

Figure 2.1 Typical NRC Snapshot of Quarterly Performance Indicators

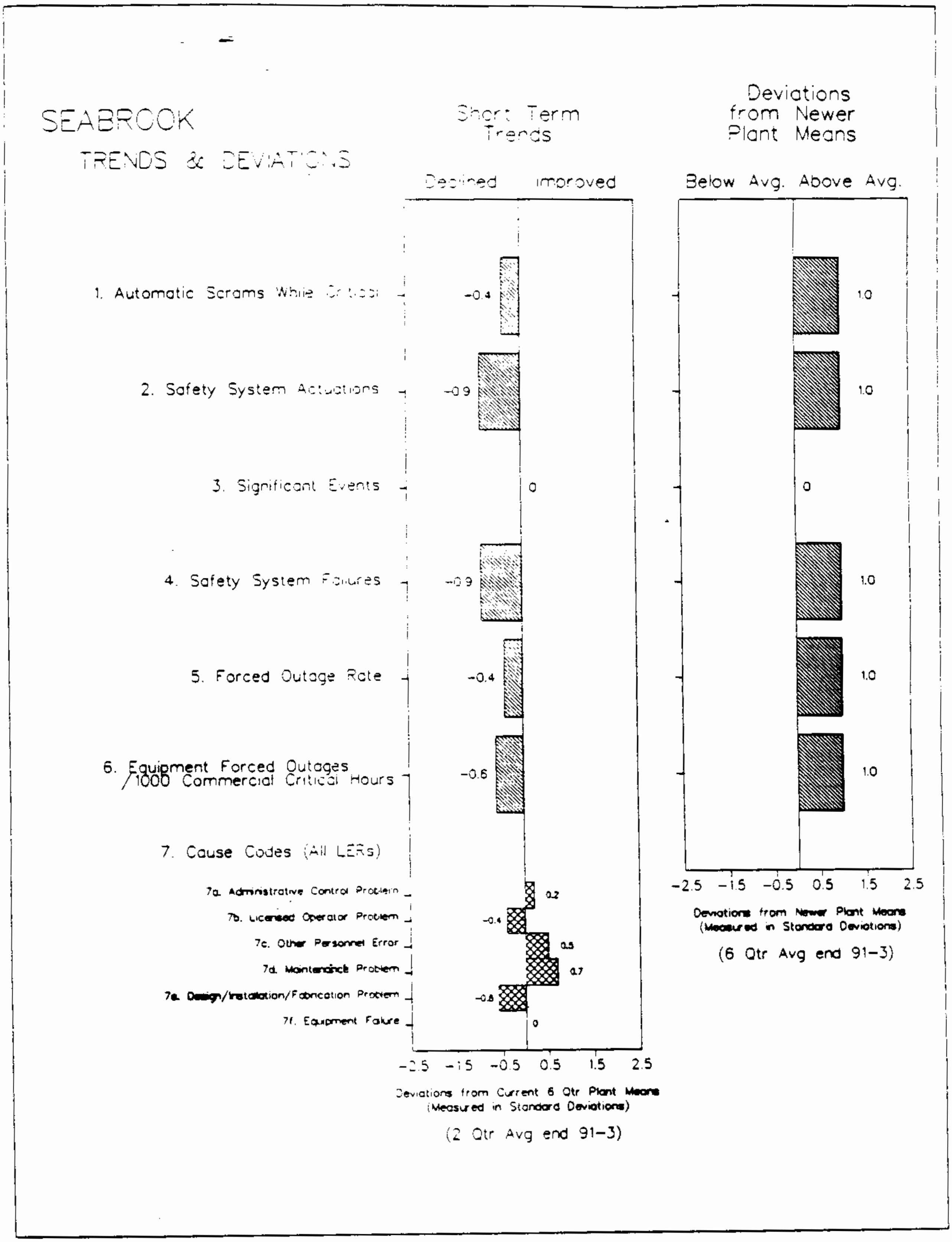

Figure 2.2 Typical NRC Performance Indicator Trend Data

Interviews with a number of INEL personnel directly involved in the NRC performance indicator program or interfacing with that program indicate a number of potential problems in drawing objective conclusions from these performance indicators. First, the indicators do not reflect the current status of the plant (e.g., whether the plant is operating, shutdown, or in startup); this information can greatly change the interpretation of events. For example, automatic scrams during plant startup are more likely and less indicative of underlying safety problems than automatic scrams during steady state operation. Second, differences in plant management style can affect the reporting of events. For example, it is possible that an organization can rationalize a forced equipment outage as being part of a planned maintenance outage. (Note that there is some inherent ambiguity in the identification of the cause of an outage.) As another example, because voluntarily reported events are not usually included in the performance indicator database (this provision is intended to encourage self-reporting of events), an organization can affect its indicator statistics by its event reporting strategy. Third, because the performance indicators are based on the occurrence of infrequent events (hence summary meaningful statistics cannot be generated much more frequently) and because they focus on historical performance (and not on causes of this performance), they are not always useful in predicting if a given plant is just starting on a downward trend.

The first problem is being dealt with by improvements in the quarterly report; the report will shortly display indicators broken down by plant operating status, as shown in Figure 2.3 [4]. It will also provide a comparison of the plant with a well-defined peer group, allowing a better evaluation of the plant's performance (see Figure 2.4). The second problem is clearly more difficult; it will probably persist as long as event data are collected by plant owners and operators. The third problem provides the basis for an NRC-sponsored research program on safety indicators, discussed below in Section 2.1.2. It should be noted that, despite the problems noted, members of the NRC staff responsible for evaluating plant performance feel that the performance indicators corroborate, at least in hindsight, the judgments made by the staff on the basis of more qualitative information (e.g., the results of routine and special inspections).

Table 2.1 shows the NRC performance indicators and how they are graded according to the classification scheme described earlier in this section. Almost all of the indicators are moderately or strongly direct indicators of safety, and most are moderately or strongly consistent. On the other hand, except for the cause codes, the indicators are focused on effects rather than causes; their ability to predict future performance therefore rests upon the assumption that underlying causes of problems do not change (or change slowly) over time.

In contrast to the performance indicator program, the NRC systematic assessment of licensee performance (SALP) program is aimed at providing a qualitative evaluation of organizational programs. (Numerical scores are assigned, but only for the purpose of indexing.) SALP ratings and trends in ratings (e.g., improving, declining) are assigned to score performance in seven functional areas:

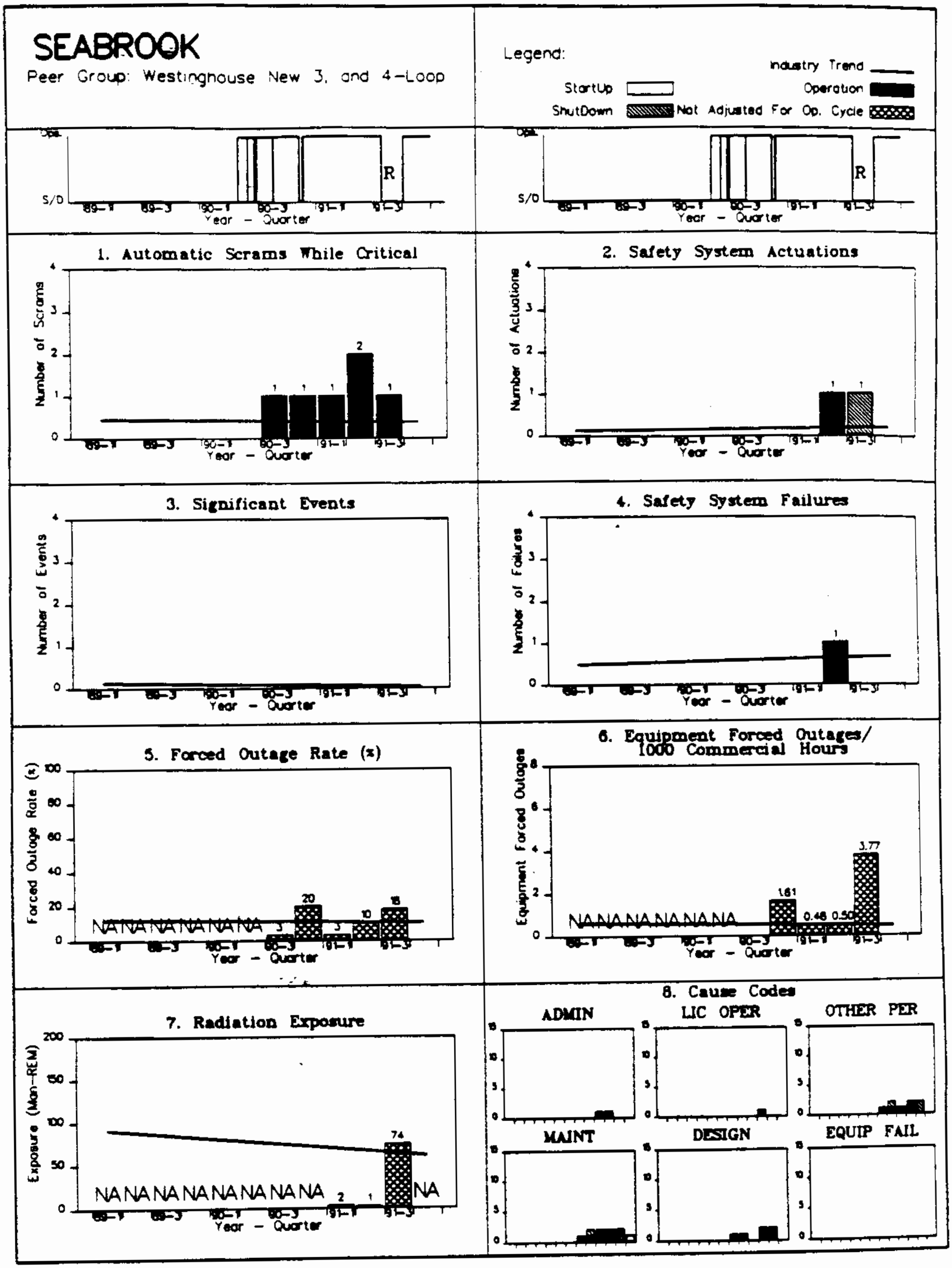

Figure 2.3 Quarterly Performance Indicator Report Showing Plant Operating Status

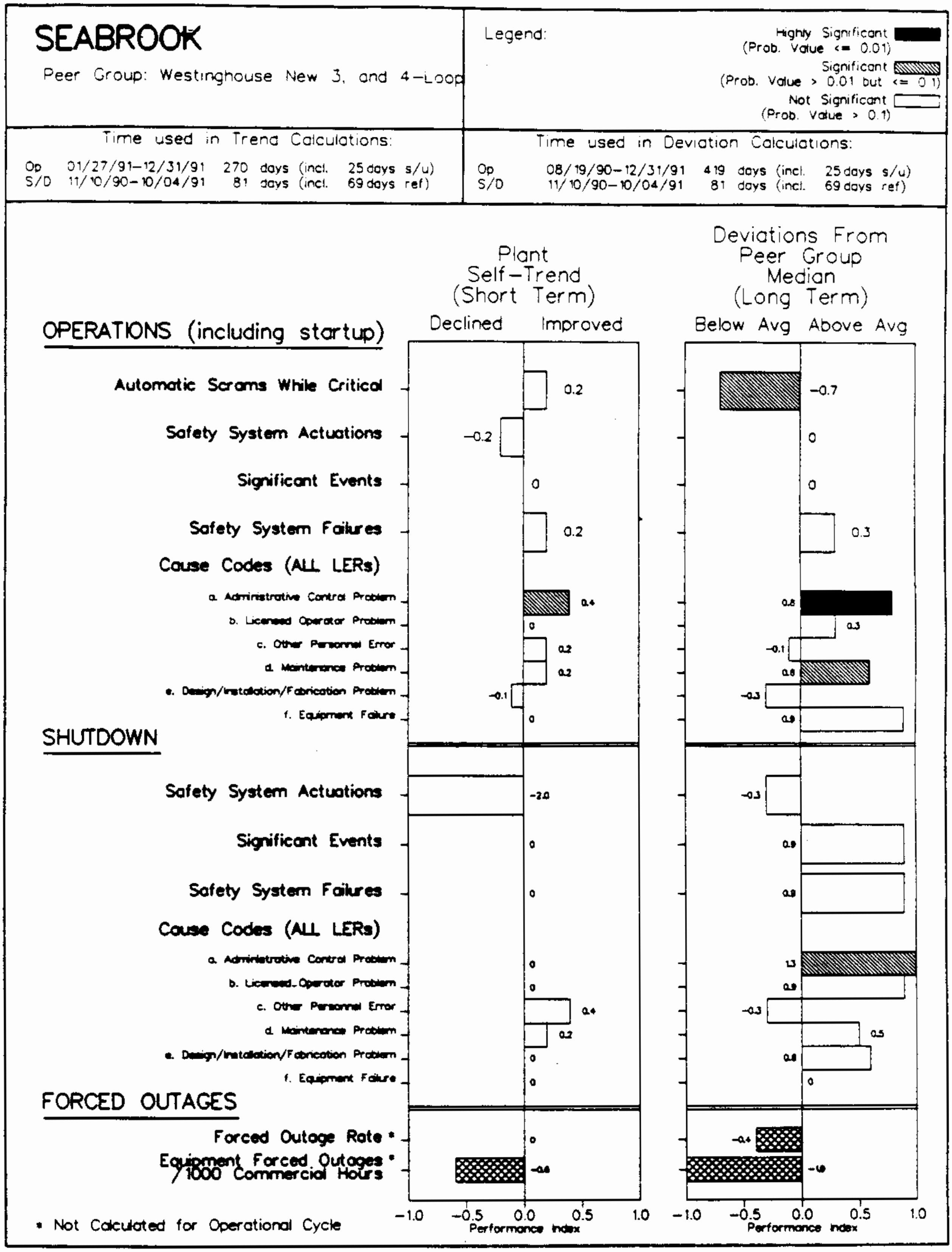

Figure 2.4 Quarterly Performance Indicator Comparison With Plant Peer Group

Table 2.1 - Characterization of Current USNRC Performance Indicators

Indicator	Directness	Predictive Power	Form	Consistency	Omissive Power
automatic scrams while critical	**Strong** Causes plant transient, challenges safeguards	**Weak** Historical, focus on effects	**Quantitative**	**Strong** Unambiguous	**Moderate** Observable event ($\lambda \approx 1/yr$); highly variable process
safety system actuations	**Moderate** Indicates challenges to safeguards, includes spurious actuations	**Weak** Historical, focus on effects	**Quantitative**	**Strong** Unambiguous	**Moderate** Observable event ($\lambda \approx 1/yr$); highly variable process
significant events	**Very Strong** By definition of "significant events"	**Weak** Historical, focus on effects	**Quantitative**	**Weak** Judgment needed to assign code	**Weak** Rare event ($\lambda << 1/yr$); highly variable process
safety system failures	**Strong** Indicates state of safeguards	**Weak** Historical, focus on effects	**Quantitative**	**Moderate** Some freedom in defining failure	**Moderate** Observable event ($\lambda \approx 1/yr$); highly variable process
forced outage rate	**Moderate** Overlaps with scrams; indicates unexpected event rate	**Weak** Historical, focus on effects	**Quantitative**	**Moderate** Some freedom in defining if outage is forced	**Strong** Countable event ($\lambda > 1/yr$)
equipment forced outages/1000 hrs	**Moderate** Overlaps with scrams; indicates maintenance practices	**Weak** Historical, focus on effects	**Quantitative**	**Moderate** Some freedom in defining if outage is forced, due to equipment failure	**Strong** Countable event ($\lambda > 1/yr$)
collective radiation exposure	**Weak** Occupational safety; indicates general attitude towards safety	**Weak** Historical, focus on effects	**Quantitative**	**Strong** Unambiguous	**Strong** Measurable statistic
cause codes	**Moderate** Highly variable safety significance	**Moderate** Indicates underlying processes	**Qualititative**	**Weak** Judgment needed to assign code	**Strong** Countable event ($\lambda > 1/yr$)

- plant operations
- radiological controls
- maintenance/surveillance
- emergency preparedness
- security and safeguards
- engineering/technical support
- safety assessment/quality verification

The ratings are assigned on the basis of information gathered over an 18-month time period. It includes daily input from the plant resident inspector and the results of specialty team inspections. These letters can look at safety review processes, radiological protection, etc. The final ratings are developed from discussions among the SALP review team. The evaluation criteria used for each of the functional areas are as follows [5]:

- assurance of quality, including management involvement and control,
- approach to resolution of technical issues from a safety standpoint,
- enforcement history,
- operational and construction events (including response to, analyses of, reporting of, and corrective actions for),
- staffing (including management), and
- effectiveness of training and qualification program.

Ref. 5 provides an example of a SALP report. Some of the factors explicitly cited in this report include management focus and involvement, initiative, communication, competence, interaction with the NRC, staffing, morale, professionalism, program effectiveness, and identification and resolution of deficiencies. However, the formal process used to derive ratings is not specified in the report. This is consistent with the results of interviews with INEL personnel familiar with the SALP program, which indicate that the review process is subjective (ratings are developed based on the judgment of the review team members).

Using the classification system described earlier and the ratings convention employed in Table 2.1, it can be seen that because the SALP ratings aim to evaluate management processes (rather than event occurrence rates), they are:

i) moderately direct indicators of safety,
ii) potentially predictive,
iii) qualitative, and
iv) weakly consistent.

Since, as discussed earlier, the issue of indicator "omissive power" relates to the willingness of an organization to report on its own problems, this characteristic is irrelevant for SALP (an external review). Note also that it is difficult to show that SALP ratings are indeed predictive since the processes they are measuring are likely to change when bad ratings are issued.

The strength of the SALP rating process is that it looks at processes that have broad ranging (if indirect) impacts on safety. A key weakness is that the rating process is quite sensitive to the judgment of review team members. Current research on organizational factors may lead to a more systematic approach, as discussed in the following section.

2.1.2 USNRC Research on Organizational Factors and Safety

The NRC has been funding research on organizational factors and their influence on safety since 1988. Recognizing that management and organizational factors have a pervasive effect on plant performance and safety, and that management and organization problems are often the root causes of accidents, the goals of the research are:

> "... to develop tools and data to support both regulator and licensee initiatives in this area [organizational factors], and a better understanding of the factors that shape organizational performance as it pertains to safety." [6]

One of the intended early products of this research program is a set of "leading" (i.e., predictive) indicators of plant safety performance. The indicators will address the four key organizational factors identified in Ref. 6 and used later in this report to evaluate available information on East European reactor performance:

- "Communication (commonly understood organizational goals across and between management and worker personnel, and means to achieve these goals)

- Organizational Learning (processes and attendant resources identifying and solving problems or prospective problems, and learning from the experience)

- Organizational Focus (management [significant other] attention and oversight, and application of available resources)

- External Factors (parent corporation, parent utility, regulating bodies)."

Ref. 6 points out that the indicator development work is guided by the need to satisfy six criteria. These criteria are used to ensure that the indicator be useful and credible. The criteria are that: a) the indicator must not require additional data collection (beyond that currently collected by the NRC or by other organizations), b) the indicator must be correlated with at least one of seven NRC performance indicators (the cause codes are excluded), c) the indicator must be credible to potential users, d) potential causal mechanisms leading to indicator fluctuations must be known, e) there must be credible information on the lag time between a fluctuation in the indicator and unacceptable safety conditions at the plant, and f) threshold acceptability levels for the indicator can be established.

The early results of the NRC research show that a number of indicators meet (or have the potential to meet) these criteria:

- major violations (evidence for organizational learning [7])
- reportable events (evidence for organizational learning [7])
- debt/equity ratio (evidence for corporate resource availability [7])
- return on assets (evidence for corporate resource availability [7])
- engineered safeguards actuations at power (evidence for maintenance [8])
- gross heat rate (evidence for maintenance program [8])
- daily power level (evidence for maintenance program [8])
- remediation i.e., corrective method (evidence for training program [9])
- instructor ratio (evidence for training program [9])
- time by subject (evidence for training program [9])
- training budget (evidence for training program [9])

The first seven indicators have been validated using NRC performance indicator data. The last four have been validated using training simulator performance data.

More recently, attention has been focused on a different but overlapping set of seven potential leading indicators [1]. Brief descriptions of these seven follow:

- corrective codes

  These codes, listed in the licensee event reports, specify the corrective action taken after an event (e.g., procedure modifications).

- inadvertent engineered safeguards actuations due to human error during testing and maintenance

  Ref. 8 states that this indicator is strongly associated with the quality of a plant's maintenance program, as measured by the relevant SALP score.

- safety system function trend

  This indicator includes the "safety system failures" indicator currently tracked by the NRC. However, it also includes other sources of unavailability (e.g., maintenance), and therefore provides a better snapshot of the plant's current level of protection against accidents.

- daily power level

  Ref. 8 points out that minor but frequent fluctuations in this indicator can indicate weaknesses in the plant's maintenance program (e.g., the use of "band-aid fixes" rather than systematic remedial actions). Although the indicator measures power production rather than safety, Ref. 8 argues that maintenance problems affecting power production (which is the plant's prime objective) will also affect plant safety equipment.

- organizational profile associated with scram frequency

  Researchers at the University of Minnesota have identified a number of factors, primarily organizational, that are statistically correlated to two of the NRC's performance indicators: number of scrams and number of safety system failures. The factors correlated to the scram rate are:

  - initial plant costs ($/W installed)
  - plant experience (yr)
  - number of scrams in prior time period

- organizational profile associated with safety system failures

  The following factors were found to be correlated with the safety system failure rate:

  - SALP score
  - number of major violations
  - return on investment
  - operational efficiency (earnings/assets)
  - relative staff size (operations staff size plus engineering staff size divided by supervisory staff size plus engineering staff size)
  - relative amount of utility's alternate power generation (as opposed to nuclear)
  - number of safety system failures in prior time period

- operations staff overtime

  The University of Minnesota researchers have also found the amount of overtime to be a potentially important leading safety indicator. The factors contributing to this indicator are:

  - overtime man-hours
  - adjusted operations staff size
  - critical hours
  - region (plant location in one of the 5 NRC regions)

Some of these indicators (or factors contributing to the indicators) are directly related to safety. Others, especially the last three, are more indirectly connected; further examination is needed to determine if the statistically determined correlations between the listed factors and the validation source (the NRC performance indicators) indicate cause-effect relationships. Note also that a number of the factors require data that may be difficult to obtain for the East European reactors. On the other hand, the prime attributes of these indicators are that they have been designed to be relatively unambiguous (and, therefore, consistent) and that they have been tested for their ability to predict variations in plant safety performance (as measured by the NRC performance indicators). Additional work is needed to determine the usefulness of these indicators in assessing the safety level of the East European reactors, and to determine if additional, more ambiguous but direct, leading indicators are needed.

2.1.3. INPO/DOE Conduct of Operations Performance Evaluation Guidelines

In the aftermath of the accident at the Three Mile Island Unit 2 reactor the U.S. nuclear industry formed the Institute of Nuclear Power Operations (INPO). One of INPO's earliest efforts was to set standards for measuring and improving nuclear facility Conduct of Operations (a term loosely borrowed from the U.S. Naval Reactors program). The U.S. Department of Energy adopted a considerable amount of this practice and formalized it under a number of DOE Orders. Examples include: Safety of Nuclear Facilities (DOE Order 5480.5), Conduct of Operations for DOE Facilities (DOE Order 5480.19). From these industry and government activities have come the recognition that good operational safety is not a result of good luck but is a result of discipline, formality, teamwork, and professionalism.

Tangible evidence of good operational safety practices are observable by looking into the following fourteen areas [10]:

- Organization and Administration
- Operations (formality)
- Maintenance
- Training and Certification
- Auxiliary Systems (safety and non-safety operability)
- Emergency Preparedness (procedures, exercises etc.)
- Technical Support
- Security/Safety Interface
- Experimental Activities (controls)
- Facility Safety Review
- Nuclear Criticality Safety
- Radiological Protection
- Personnel Protection
- Fire Protection

It is not surprising that in the development of Department of Energy Tiger Team - Technical Safety Appraisals these same items are focused on in very great depth. From the Department of Energy's Facility Surveillance Manual five indicators of underlying facility problems are identified. These five items cut across all fourteen of the above noted disciplines and are worth consideration when developing a method to screen the safety of foreign reactors. In other words, problems identified in the five indicators of underlying facility problems warrant a more in-depth review of other areas. These five indicators are:

- Inadequate Operator Knowledge
- Inattentive or Indifferent Operator Attitude

- Deficient Recordkeeping Practices
- Patterns of Personnel Errors or Injuries
- Deficient Housekeeping and Safety Practices

The relationship of these five indicators of underlying problems to the overall fourteen areas for assessing operational safety is discussed below.

Inadequate operator knowledge is a indicator of very serious facility safety problems because operators are the very first line of defense in assuring facility safety. Deficiencies in this area are an indication of weaknesses in training and certification (how did this individual get to a position of responsibility?), and organization and administration (who decided this individual could be trusted to function in a particular capacity?).

Inattentive or indifferent operator attitude is possibly the most reliable indicator of the overall health of an operating organization. Successful safe operations requires discipline, formality, teamwork, and professionalism. If an observer walks into a control room (unannounced) and finds a significant amount of non-work related activities going on - this is a clear indication that professionalism, formality, and discipline are absent. The absence of these indicate likely problems in organization and administration (does plant management know what is going on?), or operations (what operational duties are not being performed?).

Deficient recordkeeping practices are a strong indicator of "infrastructure" type problems. Lack of recordkeeping or inadequate recordkeeping can cause problems throughout the facility. Operations is impacted because of the inability to have faith in system diagrams (and possibly procedures). Maintenance is impacted because of the inability to identify past similar problems, root causes, and recommended strategies to repair or maintain equipment. Poor documentation also impacts the ability to conduct good training of operators and other plant support personnel, review planned experimental activities, conduct facility safety reviews, conduct nuclear criticality safety reviews, or maintain good radiological/personnel/fire protection programs.

When an observer identifies patterns of personnel errors or injuries at a nuclear facility,it is important to recognize that these are not just coincidental random occurrences. They are a tangible indication that the facility management is not learning from past experience. If there is not continual learning from past experience there is a management culture problem that will likely be found in many areas which effect plant operational safety.

Deficient housekeeping and safety practices are good indicators of potential problems in the areas of fire protection, personnel protection, radiological protection, auxiliary systems (availability and reliability), and maintenance in general.

Comparing the structure of the INPO/DOE scheme for evaluating facility performance with that for the SALP rating process, it can be seen that they have a number of similarities. Both are ultimately concerned with evaluating performance in a limited number of key functional areas. (The INPO/DOE scheme covers fourteen areas, whereas SALP is concerned with seven; however, some SALP categories include multiple INPO/DOE areas.) Both also look at processes that affect safety, e.g., the performance of maintenance, rather than the statistical outcomes of those processes, e.g., the number of equipment failures due to poor maintenance. Like the SALP ratings, the INPO/DOE indicators are:

i) moderately direct indicators of safety,
ii) potentially predictive,
iii) qualitative, and
iv) weakly consistent.

Finally, both the SALP rating process and the INPO/DOE evaluation scheme take a somewhat different look at the issue of organizational indicators than that employed by the NRC organizational factors researchers (see Section 2.1.2). The latter start by acknowledging processes basic to organizations (e.g., organizational learning) but end up with statistically quantifiable indicators. The SALP and INPO/DOE approaches start with a more pragmatic identification of key areas to evaluate organizational performance but end up with qualitative ratings and indicators. A potential problem with the research-based approach is that the statistical indicators are only indirect measures of the important processes. A potential problem with the SALP and INPO/DOE approaches is that, since they are not based on any formal theory of organizations, they may not be as complete as desired. For example, because of the emphasis on functional areas, it is possible that cross-functional issues symptomatic of basic organizational flaws may not be addressed.

2.1.4 Other Performance Indicators

Numerous other performance indicator measurement systems have been developed besides the NRC/AEOD indicators discussed in Section 2.1.1. As might be expected, these measurement systems have overlapping sets of indicators. Two additional sets of measures mentioned here are the Institute for Nuclear Plant Operations (INPO) performance indicators and the Unipede (International Union of Producers and Distributors of Electrical Energy) performance indicators.

There are 10 INPO indicators: equivalent availability, safety system performance, unplanned automatic scrams while critical, unplanned safety system actuation, forced outage rate, thermal performance, fuel reliability, collective radiation exposure, volume of low-level solid radwaste, and industrial safety lost-time accident rate [11]. It can be seen that this set strongly overlaps the NRC's set of performance indicators.

The Unipede indicators were developed by seven western European countries in an expert working group. The indicators are intended to measure performance in four specific areas. These areas are: availability and quality of service, nuclear safety, security and protection of personnel, and environment. The eight main performance indicators in the Unipede system are: "unit capability factor, safety system performance, frequency of unplanned reactor scrams per 1,000 hours, unplanned incapability factor, fuel reliability, personnel dosimetry, frequency of occupational accident rate, and frequency of unplanned turbine trips" [11]. The Unipede indicators are relatively new (initial development began around 1988) and it is unknown whether this system will be widely used in the future.

Both the INPO and Unipede performance indicators have NRC counterparts. Thus, they have the general characteristics shown in Table 2.1. Unlike the NRC system, neither the INPO nor the Unipede systems include indicators that measure underlying processes.

2.2 Data Sources

As discussed in Section 2.1, a large amount of safety indicator information is gathered and analyzed in the U.S. This section describes available data that can be used to assess the safety of Eastern European reactors.

2.2.1 Published Operational Data

Several sources of accessible data exist for Eastern European nuclear plants. For the most part, these sources are readily available in technical or scientific libraries. In Table 2.2 is a list of five references which were found to contain information concerning the operation of nuclear plants outside the U.S. A summary of the type of information contained within each reference is provided, along with the publisher of the document.

It was found that the first reference in Table 2.2 contained the most pertinent data for this study. This International Atomic Energy Agency (IAEA) document, Operating Experience with Nuclear Power Stations in Member States [12], contains detailed operational information for power plants in several countries, including Bulgaria (Kozloduy plants), Czechoslovakia (Bohunice plants), and Hungary (Paks plants). This information includes data under 8 different headings: station details, monthly performance data, summary of operation, historical summary, outages, outage analysis by cause, and equipment related outages analyzed by system. Figure 2.5 shows an example of the data that is included under these eight headings. The data from this document is the primary source for the data analysis contained in Subsection 2.3.1.

As mentioned in Table 2.2, the IAEA document is published annually, with the first issue being published in 1971. Thus, this reference provides a long-running history of plant operations (for those plants which are in member states), and to some extent, of plant safety.

As an aside, it should be pointed out that most of the sources listed in Table 2.2 are concerned primarily with power production. Thus, safety issues are directly addressed only when they cause an outage and thereby affect this production. (Both energy production and safety are, of course, affected by maintenance. Therefore, energy production indicators do provide an indirect indication of safety level.) In order to provide a firmer evaluation of the safety of the Eastern European plants, more direct statistics along the lines of the NRC's performance indicators (e.g., on safety system inadvertent actuations and failures on demand) are needed. This issue is further discussed in Chapter 3.

It should also be noted that because there are significant regulatory differences between the Eastern European plants and the U.S. plants, direct comparisons of performance indicators can be misleading. For example, the U.S. plants have configuration control requirements (the "Limiting Conditions of Operation") which require plant shutdown when certain standby safety equipment fail, rigorous inservice testing and inspection which significantly lengthen outage periods, and strict event reporting requirements. The statistical comparisons made in this report therefore deal only with relative differences between Eastern European plants; U.S. plant statistics are not used as a baseline for a more absolute performance evaluation.

2.2.2 Anecdotal Evidence

Anecdotal information, i.e., informal information not generally amenable to statistical analysis, is often useful for providing insights into areas not covered by other, more formal sources. In this work, the anecdotal information reviewed takes many forms, including: records of direct observations of a given plant (including written notes and photographs), the results of formal and informal discussions with facility and outside personnel, qualitative descriptions of key events, and formal presentations by members of the plant utility and regulators. The last category is discussed further in the following section. Note that although statistics for variables only indirectly related to safety (e.g., hardware costs vs. personnel costs at a unit, average years of experience of shift personnel) are not technically anecdotal information, they are currently used in the same qualitative manner. (They are used to provide safety insights, but not to generate formal, quantitative assessments of safety. This usage may change in the future, depending on the research developments in the area of leading, organizationally-based indicators.)

A key source of anecdotal information is provided by site inspections. Frequently a skilled observer inspecting a nuclear facility comes across something not originally on an inspection plan, such as an ongoing procedural violation or unsafe act. Such information should be pursued to determine if there are deeper problems.

A potential problem with interpreting anecdotal information lies in the fact that different anecdotes are collected at different facilities, yet one really wants to draw comparisons based on equivalent information. This problem is frequently encountered by NRC resident and regional inspectors. As an example, a regional inspector visits Plant A and is impressed with a maintenance work order tracking system implemented by the facility. The following week the same inspector visits Plant B and is approached by an engineer who has a safety concern and claims that his management is trying to silence him. Based on this information alone, should the inspector assume Plant A's management is proactive while Plant B's management is unethical? Obviously not. What the inspector should do is go back and see if Plant A's maintenance became more effective after implementation of their work order tracking system and examine how the various safety review committees at Plant B consider a dissenting professional position.

More generally, anecdotal information is usually information provided without a statistical context. It tends to have the characteristics of an isolated snapshot, and may not be as representative of the overall plant's performance picture as a long term numerical average. On the other hand, it clearly is of great importance for addressing issues not easily dealt with by statistical analysis and for dealing with situations where statistics are unavailable.

2.2.3 Utility and Regulatory Self Reports

Although most published operational data described in Section 2.2.1 is compiled by outside bodies based on event reports prepared by utilities, self reports from utility or regulatory representatives can be useful. With increasing professional contact between eastern European and western nuclear professionals, descriptions of unpublished events or personal descriptions of the prevailing safety culture are becoming more available. Such reports can be informal or incomplete, but help in developing a more complete understanding of safety issues by complementing the published record or by more fully describing the context in which plant safety management activities are carried out.

One example of a forum for this kind of interchange was the United States Executive Workshop on Nuclear Safety and Power Sector Reform in Eastern and Central Europe held in Washington, D.C. over the dates of September 8-11, 1992 and sponsored by the U.S. Agency for International Development. This workshop was attended by a number of prominent officials of utilities and regulatory bodies in Hungary, Bulgaria, Romania, the CSFR, and other countries. Although the papers and discussions presented at the workshop contained no dramatically important new insights, the presentations helped add to a developing understanding of the nuclear safety culture in those countries. Some examples of points made by speakers include:

- It is recognized that safety can be achieved and maintained only if adequate financial resources exist to cover maintenance, spare parts, plant backfits, training programs, etc. Further it was acknowledged that fundamental changes in rate structures and other economic factors are necessary to bring about financial health in some countries.

- There is a need for upgrades to physical security and safeguards.

- Extensive analyses of severe accident behavior must be done for operating reactors throughout the region.

- A general awareness of the design vulnerabilities of the Soviet designed VVER reactors exists.

- A good awareness of safety issues being analyzed in the west exists. Examples include pressurized thermal shock, seismic design issues, accident management issues and strategies, and beyond design basis thermal hydraulic analysis.

- Operating procedures and emergency planning at Kozloduy (and likely at other plants) are not up to the standards of western safety programs.

Self reports on plant performance and safety have appeared in other forums as well. For example, Ref. 17 describes the system used in Czechoslovakia to record and evaluate operational events. It points out that around 40-50 unusual events (generally production related) occur per unit year. The licensee event reports (LERs) for these events are assessed by a committee on a monthly basis. At this time, responsibilities are allocated and corrective measures taken. The LERs are also used as input for a national system of evaluation. This system looks at root causes (the LERs tend to focus on direct causes), at subsequent occurrences, and at potential safety significant consequences. Events are evaluated by the regulatory staff (independent of utilities), using additional records from unit process computers, operator interviews, log books, instrumentation records, independent computer analyses (e.g., for thermal hydraulics). Ref. 17 also provides descriptions of a number of past events with "high" safety significance that have been reported to the IAEA Incident Reporting System. However, the author points out that the feedback from these events is not being taken as seriously as it should be, and suggests that the regulators should impose corrective measures. (Note that the author is from the regulatory agency.)

Table 2.2 Published sources of operational data for non-U.S. reactors.

Reference (Publisher)	Type of information
Operating Experience with Nuclear Power Stations in Member States (IAEA) [12]	This yearly document presents operating information for member state's nuclear power plants. The data is compiled directly for the IAEA's Power Reactor Information System (PRIS). Information includes; load, operation, and availability factors; planned and unplanned unavailability; plant capacities and net energy produced; shutdowns and outages; plant type; and equipment related outages.
World Nuclear Performance (McGraw Hill Publications) [13]	This monthly document presents information for nuclear power plants in the "free" world. Unfortunately, this publication was unavailable so it is unknown if it includes information for Eastern European reactors. Information includes; net and available generation; heat rates; outage times; capacity and availability; plant type; and regulatory data.
Nuclear Engineering International-World Nuclear Industry Handbook (Reed Business Publishing Group) [14]	This document is an annual supplement to Nuclear Engineering International. The data is gathered from approximately 350 reactors from several countries. Comecon countries (excluding Hungary) are not included. Information includes: load factor, net-energy generated, energy capacity, and plant type.
Inside NRC (McGraw Hill Publications) [15]	This document provides limited anecdotal information concerning how non-U.S. reactor operations may influence or concern the NRC. No operational data for non-U.S. reactors is present in this publication.
Nucleonics Week (McGraw Hill Publications) [16]	This document provides limited anecdotal information concerning the operation on some non-U.S. reactors and regulatory agencies. Limited data for non-U.S. reactors are published, including: capacities, net-energy generated, and capacity factors.

CS-14 BOHUNICE-4

Operator :- EBO (ELECTROSTATION BOHUNICE)
Contractor :- SKODA -(SKODA CONCERN NUCLEAR POWER PLANT WORKS)

1. Station Details

Type :- PWR
Maximum Net Capacity at the beginning of 1990:--------- 408.0 MW(e)
Design Net Capacity:------- 398.0 MW(e)
Design Discharge Burnup:--- 28600 MW.d/t

2. Production Summary 1990

Energy Production:----- 2873.8 GW(e).h
Energy Avail. Factor:--- 80.7%
Load Factor:------------ 80.4%
Operating Factor:------- 84.8%
Energy Unavail. Factor:- 19.3%
Total Off-line Time.---- 1333 hours

3. 1990 Monthly Performance Data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
GW(e).h -	297.7	261.0	273.9	286.6	101.7	0.0	240.9	281.2	282.8	290.6	282.5	274.9	2873.8
EAF(%) -	99.4	96.2	90.8	99.9	29.3	0.0	81.3	95.4	99.1	96.5	97.1	91.7	80.7
LF (%) -	98.1	95.2	90.4	97.6	33.5	0.0	79.3	92.6	96.1	95.7	96.2	90.6	80.4
OF (%) -	100.0	100.0	93.5	100.0	35.6	0.0	90.9	97.7	100.0	100.0	100.0	99.9	84.8
EUF (%) -	0.6	3.8	9.2	0.1	70.7	100.0	18.7	4.6	0.9	3.5	2.9	8.3	19.3
PUF (%) -	0.0	1.0	0.0	0.0	69.9	107.8	15.3	0.0	0.0	0.0	0.0	7.6	16.8
UUF (%) -	0.0	1.4	7.8	0.0	0.1	0.0	2.0	2.7	0.1	0.0	0.0	0.0	1.2
XUF (%) -	0.6	1.3	1.5	0.0	0.6	0.0	1.4	1.8	0.8	3.5	2.9	0.8	1.3

4. 1990 Summary of Operation

THE OPERATION OF THE UNIT 4 WAS SAFE AND RELIABLE IN 1990. POWER GENERATION DECREASE DURING THE YEAR WAS DUE TO LEAKS FROM THE SECONDARY CIRCUIT, FROM 400 KV DISCONNECTOR CONTROL MECHANISM, FROM UNIT TRANSFORMER UPPER FLANGE, DUE TO TESTS OF REACTOR AND TG PROTECTIONS AND INTERLOCKS, DUE TO PRIMARY COOLANT FLOW DECREASE (THE CORRECTION OF MCP IMPELLERS) AND HIGH TEMP. OF COOLING WATER. THE SHORT CIRCUIT IN SERVICE WATER SYSTEM CONTROL CABLES RESULTED IN A LOSS OF ALLMCPS AND IN ACTUATION OF THE FAST REACTOR SCRAM HO-1. REACTOR POWER PROTECTION WAS ACTUATED TWICE WITH SCRAMS IN 1990.

5. Historical Summary

Date of: Construction Start:- Dec 1976
First Criticality:- 2 Aug 1985
Grid Connection:- 9 Aug 1985
Commercial Operation:- 18 Dec 1985

Lifetime Generation:------------ 13320.3 GW(e).h
Cumulative: Energy Avail. Factor:-- 81.0%
Load Factor:----------- 80.9%
Operating Factor:------ 85.0%
Energy Unavail. Factor: 19.0%

YEAR	ENERGY GW(e).h	CAPACITY MW(e)	PERFORMANCE FOR FULL YEARS OF COMMERCIAL OPERATION: ENERGY AVAIL. FACTOR %		LOAD FACTOR %		ANNUAL TIME ON LINE	
			ANNUAL	CUMUL.	ANNUAL	CUMUL.	HOURS	OF (%)
1985	1083.5	408.0						
1986	2887.9	408.0	81.0	81.0	80.8	80.8	7294	83.3
1987	3084.7	408.0	86.1	83.6	86.3	83.6	7783	88.8
1988	2786.5	408.0	77.8	81.7	77.7	81.7	7248	82.5
1989	2827.7	408.0	79.2	81.1	79.1	81.0	7548	86.2
1990	2873.8	408.0	80.7	81.0	80.4	80.9	7427	84.8

Figure 2.5. Example of the operational data contained in the IAEA document "Operating Experience with Nuclear Power Stations in Member States." (Page 1 of 2)

CS-14 BOHUNICE-4

6. 1990 Outages

DATE	HOURS	GW(e).h	TYPE	CODE	DESCRIPTION
10 Feb	34.0	6.6	PP	E41	TESTS OF TG 41, 42 PROTECTIONS AND INTERLOCKS AND THE SEPARATOR-REHEATER INLET PIPE LEAK REMOVAL
21 Mar	59.0	23.5	UF	A32	THE RAISING OF LEAKS ON THE SECONDARY CIRCUIT DURING TRANSIENT STATES (FLANGE JOINTS), FAILURE OF 400 KV DISCONNECTOR DUE TO THE RUPTURE OF RUBBER PACKING ON THE CONTROL MECHANISM
12 May	1256.0	575.4	PF	C	REFUELLING COMBINED WITH GENERAL MAINTENANCE AND REPAIRS
20 Jul	19.0	3.3	UP	A42	OIL LEAKAGE FROM PENETRATIONS OF TRANSFORMER AT 01
29 Aug	20.0	8.0	UP	A42	THE FAST REACTOR SCRAM HO-1 DUE TO THE LOSS OF ALL MCPS WHICH WAS CAUSED BY SHORT CIRCUIT IN CABLES FOR SERVICE WATER SYSTEM CONTROL
6 Dec	107.0	23.0	PP	D42	PLANNED REPAIR OF TRANSFORMER AT 01

7. Full Outages, Analysis by Cause

OUTAGE CAUSE	1990 HOURS LOST			1986 TO 1990 AVERAGE HOURS LOST PER YEAR		
	PLANNED	UNPLANNED	EXTERNAL	PLANNED	UNPLANNED	EXTERNAL
A. Equipment Related		59			51	
C. Refuelling	1256			1159		
D. Planned Maintenance				34		
E. Testing				4		
Subtotals	1256	59	0	1197	51	0
TOTAL	1315			1248		

8. Equipment Related Full Outages, Analysis by System

SYSTEM	1990 HOURS LOST	1986 TO 1990 AVERAGE HOURS LOST PER YEAR
12. Reactor Control Systems and Instrumentation		2
15. Reactor Cooling and Steam Generation System		2
16. Steam Generators		23
32. Feedwater and Steam System	59	17
Miscellaneous Causes		7
Total	59	51

Figure 2.5. Example of the operational data contained in the IAEA document "Operating Experience with Nuclear Power Stations in Member States." (page 2 of 2)

It is anticipated that as similar workshops and conferences are presented in the future, there will be increased opportunities for direct personal interaction with representatives of these countries' nuclear programs and for developing the kinds of insights that result from such interaction.

2.3 Data Analysis

This section describes an analysis of performance data collected for the Kozloduy and Bohunice plants and presents subjective impressions of the plants and their management. These two plants employ roughly the same type of reactor (note that Kozloduy Units 1-4 and Bohunice Units 1 and 2 are VVER-440 Model 230's; while Bohunice Units 3 and 4 are VVER-440 Model 213's) but appear to be operated with considerably different styles in management. The purposes of the comparison are threefold: (a) to provide a preliminary evaluation of two important plants based on available information, (b) to investigate the degree to which the various sources of information corroborate each other, and (c) to identify additional information needed to strengthen the evaluation. The last two points are discussed in Section 3.

Section 2.3.1 provides a statistical analysis for the two plants, looking at both long term averages and recent trends in data reported to the IAEA (see Section 2.2.1). Section 2.3.2 provides some preliminary insights concerning plant design (including a comparison of the two Bohunice VVER-440 Model 230's with the two Bohunice VVER-440 Model 213's) and Section 2.3.3 does the same for the two plants' organizations. The discussions in both of these sections are based solely on the operational performance information described in Section 2.2.1. On the other hand, Section 2.3.4 evaluates two plants using the direct observation and anecdotal information described in Section 2.2.2.

2.3.1 Statistical Performance Evaluation

The data evaluation for this study was begun by collecting historical operational information (from Ref. 12) for five PWRs. These five PWRs are rated at the same nominal net power level of 408 MW(e). Table 2.3 lists the five power plants, their country of operation, and their respective power capacity (at the end of 1989). One important feature about these plants is that they are all of the Model 230 design. The data that was collected spanned the years 1982-1990 with one exception; no data was available for the Bohunice plants in 1982.

The historical data for the five plants is contained in Appendix I. Also contained in Appendix I is a historical plot of nine performance indicators collected for each group of plants.

Table 2.3. Power plants selected for demonstrating the data gathering and analysis.

Plant	Country	Power Capacity, MW(e)
Kozloduy 1	Bulgaria	408
Kozloduy 2	Bulgaria	408
Kozloduy 3	Bulgaria	408
Bohunice 1	Czechoslovakia	408
Bohunice 2	Czechoslovakia	408

2.3.1.1 Long Term Averages

The long term averages (from 1983-1990 for the Bohunice plants and 1982-1990 for the Kozloduy plants) for the five plants were developed from the data contained in Reference 12. These averages were developed for six indicators. These indicators are:

- Load factor (net energy produced/maximum net energy producible)
- Number of equipment-caused outages per year
- Refueling duration
- Outage time for planned maintenance
- Total outage time for unplanned maintenance (which result in a full outage)
- Number of leak events per year (which result in an outage)

The load factor is a measure of plant productivity. Although not directly associated with safety, it provides an indication of the extent to which the plant is being pushed to its limits. The number of equipment-caused outages per year indicates the effectiveness of maintenance. The refueling duration is of interest since a large amount of maintenance is typically performed during refueling outages; shorter outages allow increased energy production, but can come at the expense of needed repairs. The outage time associated with planned maintenance is a further indicator of the willingness of the plant to perform maintenance despite a loss of energy production. The outage time for unplanned maintenance and the number of leak events (i.e., the number of outages caused by leaks) are statistics similar to the number of equipment-caused outages per year in that they reflect the effectiveness of maintenance.

All of these statistics are either reported directly in Ref. 12 or can be determined unambiguously from the material presented in that reference. For example, the number of leak events per year are counted using the outage descriptions (see Figure 2.5).

Appendix I contains the actual data that was used to generate the averages. Table 2.4 contains the calculated averages for each plant and aggregate averages for the two plant groups (Bohunice 1-2 are one group while Kozloduy 1-3 are the second group). One note is that leak events are defined as any leak which causes an outage. These leaks include not only leaks from the stem generators and secondary side, but also hydrogen leaks, oil leaks, pressure vessel leaks, and seal leaks.

Table 2.4. Long term annual indicator averages for the evaluated plants.

Plant	Load factor	# equipment caused outages (/year)	Refueling outage duration (hours)	Planned maintenance (hours)	Unplanned maintenance (hours)	# of leak events (/year)
Bohunice 1	74.7%	4.3	1250	189	249	3.3
Bohunice 2	78.0%	3.5	1192	210	75	2.6
Bohunice 1-2	76.4%	3.9	1221	199	162	2.9
Kozloduy 1	75.4%	3.1	1139	48	23	1.7
Kozloduy 2	74.0%	3.3	1003	136	146	1.8
Kozloduy 3	78.7%	2.7	1004	20	31	1.6
Kozloduy 1-3	76.0%	3.0	1049	68	67	1.7

Several important observations can be quickly ascertained from evaluating the information contained in Table 2.4. First, the average long term load factors for the two plant groups are very close, which would imply that the plants, on average, are producing about the same amount of energy. Second, the refueling and planned maintenance times are significantly shorter for the Kozloduy plants when compared to the Bohunice plants (by almost 13 days per year). Third, the average outage time for unplanned maintenance is significantly shorter for the Kozloduy plants than for the Bohunice plants. And fourth, while the number of leak events for the Bohunice plants are almost twice as frequent as the events for the Kozloduy plants, the average number of events between plants in the same group (especially Kozloduy) are very similar. The implications of these observations are discussed in Sections 2.3.2 and 2.3.3.

2.3.1.2 Recent Averages

The recent averages (from 1987 to 1990 for the Bohunice and Kozloduy plants) for the five plants were developed from the data contained in Reference 12.

Table 2.5 contains the calculated averages for each plant and aggregate averages for the two plant groups.

Table 2.5. Recent annual indicator averages for the evaluated plants.

Plant	Load factor	# equipment caused outages (/year)	Refueling outage duration (hours)	Planned maintenance (hours)	Unplanned maintenance (hours)	# of leak events (/year)
Bohunice 1	72.6%	4.8	1521	76	327	3.8
Bohunice 2	78.1%	5.5	1176	149	119	3.8
Bohunice 1-2	75.4%	5.1	1348	112	223	3.8
Kozloduy 1	73.3%	5.8	1274	23	6	3.0
Kozloduy 2	68.0%	5.8	1149	268	207	3.3
Kozloduy 3	76.2%	5.3	1294	0	53	3.0
Kozloduy 1-3	72.5%	5.6	1239	97	89	3.1

Several important observations can be determined by contrasting Tables 2.5 and 2.4. First, the recent load factors for the two plant groups have decreased from the long term average. Second, the number of equipment caused outages has increased. Third, while the outage times due to refueling, planned maintenance, and unplanned maintenance have increased slightly for the Bohunice plants (from the long term average), the average outage time for the Kozloduy plants has increased from the long term average by over 10 days. Fourth, the number of reported leak events has increased for both plant groups. And fifth, the number of leak events is still very similar for each plant within a group.

One additional interesting note is that both Kozloduy 1 and Kozloduy 3 have higher refueling durations than the Kozloduy 2 unit during the 1987-90 time frame. This increase for Units 1 and 3 may be attributable to the fact that both Units 1 and 3 undertook annealing of the reactor pressure vessel during the 1989 refueling outage.

2.3.2 Preliminary Plant Design Inferences

It was hypothesized that an operational difference may be found between different types of plants (i.e., VVER-440 Model 230 versus VVER-440 Model 213) when looking at the historical data. To determine the extent of this operational difference, the data for the Bohunice plants (both Units 1 and 2, which are VVER-440 Model 230s, and Units 3 and 4, which are VVER-440 Model 213s) were evaluated. Table 2.6 shows the results of the evaluation for the six performance indicators discussed previously.

Table 2.6. Recent annual indicator averages for the Bohunice 1-4 plants.

Plant	Load factor	# equipment caused outages (/year)	Refueling outage duration (hours)	Planned maintenance (hours)	Unplanned maintenance (hours)	# of leak events (/year)
Bohunice 1	72.6%	4.8	1521	76	327	3.8
Bohunice 2	78.1%	5.5	1176	149	119	3.8
Bohunice 1-2	75.4%	5.1	1348	112	223	3.8
Bohunice 3	74.6%	2.3	1238	503[a]	105	0.5
Bohunice 4	80.9%	2.8	1167	6	33	1.5
Bohunice 3-4	77.8%	2.6	1203	255	69	1.0

[a] This value is exceptionally high due to the fact that during the second full year of operation (1987), 2010 hours of planned maintenance was performed (which then caused the 1987-90 average to be abnormally high). This large amount of maintenance may be attributable to the "breaking-in" of a new plant.

Once again, several observations can be made using Table 2.6. First, it appears that the VVER-440 Model 213 plants (i.e., Units 3 and 4) have a slightly higher capacity factor. Second, the VVER-440 Model 213 plants have almost half as many equipment-caused outages when compared to the VVER-440 Model 230 plants (i.e., Units 1 and 2). Third, the time for refueling seems to be slightly lower for the VVER-440 Model 213 plants. Fourth, while the planned maintenance for the VVER-440 Model 213s appears to be much higher, if one anomalous point (i.e., the 2010 hours of maintenance discussed in the footnote above) is dropped from the average, the overall average for planned maintenance for units 3 and 4 would only be 3.1 hours (per year). And fifth, both the unplanned maintenance times and the number of leak events for the VVER-440 Model 213s appear to be significantly lower than for the VVER-440 Model 230 plants. It therefore appears that, based upon the IAEA data, there are indeed performance differences (and possibly safety differences) between the two models. Note that a preliminary analysis which compensates for the different plant ages yields similar results.

One additional potential design insight comes from an earthquake in 1990 at the Kozloduy site. During this earthquake Units 1, 2, and 3 tripped automatically while Unit 5 (a VVER-1000) was manually shutdown (Unit 4 was in refueling). Unfortunately, no additional information was available to be able to discern why the newer plant (Unit 5) was manually shutdown while the VVER-440 Model 230 units (Units 1-3) tripped automatically. Further work might reveal if Unit 5's trip signals were indeed actuated, or if the manual trip was performed as a precautionary measure.

2.3.3 Preliminary Organizational Inferences Based on IAEA Data

The IAEA data described in Section 2.2.1 and analyzed in Section 2.3.1 are intended to provide objective statistics characterizing plant performance. However, this section shows that a number of insights concerning the four organizational characteristics identified by researchers on organizational factors in nuclear plant safety and listed in Section 2.1.2, i.e.,

- organizational focus
- communication
- organizational learning
- external factors

can also be drawn from the data. These insights are based largely on qualitative aspects of the data, such as the types of events reported and the quality of event reporting. They are also based on assessments of the reported level of key safety-related processes (e.g., preventive maintenance).

Organizational Focus

In this analysis, the key question concerning organizational focus is whether the Bohunice and Kozloduy organizations place a strong priority on safety. Based on the IAEA data alone, definitive answers to this question cannot be derived. However, some insights concerning the relative importance of safety to the two organizations can be developed. In particular, it appears that Bohunice places a higher priority on safety (relative to energy production) than does Kozloduy. This can be seen from a number of pieces of evidence.

- The Bohunice plants perform a significantly greater amount of planned maintenance.
- The Bohunice plants are placed in a partial or full outage condition for more minor events; in the long run, they also undergo more equipment related outages (partial and full).
- The Bohunice annual descriptions of operations provided to the IAEA data base are somewhat more carefully prepared and provide more information.

The first bullet follows from the statistics presented in Tables 2.4 and 2.5. The Bohunice plants generally have more planned maintenance outages, spend more time in planned maintenance, and spend more time in refueling outages (which are usually used to perform planned maintenance as well as refuel the reactor). Additional downtime due to maintenance clearly has a positive effect on safety and a negative effect on energy production. The two plants considered, in treating this trade-off differently, appear to be reflecting differences in management philosophy (in terms of direct emphasis on safety, in terms of resources provided to ensure safety, or both).

Similarly, the second bullet apparently reflects philosophical differences in the treatment of problems. A willingness to take a plant out of service to fix minor problems reflects a greater emphasis on safe operation.

The third bullet stems from two observations. First, the Bohunice entries into the IAEA data base include summaries of the year's key events. This includes information on automatic scrams (an NRC performance indicator) which is not explicitly requested by the data base. The Kozloduy entries generally do not include these summaries. As a direct consequence, the annual number of automatic scram actuations cannot be determined. Second, the Kozloduy estimates of energy lost during partial outages consistently correspond to a reactor power level that is 50% of the nominal full power rating. While the plant design lends itself naturally to 50% outages (it has two turbine-generators), actual outages are expected to vary considerably according to the circumstances of the outage. Indeed, the Bohunice partial outages correspond to a variety of power levels. Both observations seem to be innocuous. However, we suggest that the differences in reporting quite possibly reflect different attitudes towards safety. One plant (Bohunice) appears to treat data reporting more seriously, implying awareness of the importance of learning from mistakes outside as well as within the organization. The other plant (Kozloduy) appears to take a more casual approach.

It should be pointed out that there are alternate interpretations to the three bullets. Despite the nominal similarities between the Kozloduy and Bohunice plants, it may be that the latter simply have more problems (and therefore require more maintenance-related outages). Regarding the quality of the event reporting, it is possible that the information provided to the IAEA is filtered during translation by personnel unconnected with the plant organizations. The insights drawn from the data review are derived employing reasonable judgment, but clearly are preliminary until bolstered by corroborative information. Some such information is described in Section 2.3.4.

It is also interesting to note that, despite the apparent differences in safety culture in the two organizations, the Kozloduy and Bohunice plants are producing energy at about the same level (their load factors are roughly equal). This seems to show that, resources permitting, the Kozloduy plant could be run more safely without sacrificing significant energy production.

<u>Communication</u>

As defined in Ref. 6, "communication" includes both the communication of goals within an organization and the provision of resources to achieve these goals (provision of resources is a form of communication since it informs the staff about the depth of management commitment towards the stated goals). In this sense, the high load factors (i.e., capacity factors) and relatively short refueling outage durations for the Kozloduy and Bohunice plants demonstrate a strong communication process concerning the goal of energy production. On the other hand, as mentioned above, because the operations at Kozloduy do not reflect as great a concern with safety as at Bohunice, it can be inferred that either: a) there is truly a lesser concern, or b) such concerns are not being properly communicated to the staff.

The discussion in Section 2.3.4 based on direct observations at Kozloduy and Bohunice will provide additional insights into this matter.

Organizational Learning

The IAEA data show that both the Kozloduy and Bohunice plants appear to have problems learning from experience. Specifically, over the last 10 years, both plants have had numerous repeat failures involving flange and seal leaks, especially in the turbine generator and steam generator systems. In several instances, problems with systems repaired at one point in time were experienced during later operation. Leaks especially appear to be a recurring problem.

It is not clear if the lack of improved performance with respect to recurring problems is due to an actual lack of learning or to the lack of resources to apply lessons learned. Regardless, the outcome is the same, and could have important safety implications. Note that of the two plants, Bohunice appears to have a better attitude towards learning and information disclosure, as evidenced by its more thorough treatment of event reporting to IAEA. This is further discussed in Section 2.3.4.

External Factors

Because of the focus of the IAEA data on plant performance statistics, it is difficult to separate the impact of such external bodies as the parent utility from that of the actual plant organization. It can only be pointed out that the Kozloduy plants report some instances where power output was restricted due to regulatory involvement, whereas the Bohunice plants have none such occurrences. Whether or not this implies a more active, involved regulatory body at Kozloduy is unclear.

2.3.4 Inferences from Direct Personal Observation

As a part of other Department of Energy related activities, an INEL team member visited both the Jaslovské Bohunice Station in Trnava CSFR during January 1992 and the Kozloduy Station in Kozloduy Bulgaria during May 1992. The purposes of these one-week visits were to conduct training of utility and regulatory body personnel in operational safety and inspection techniques typical of those employed in the United States. The trip reports from these visits are documented in Refs. 18 and 19. The following observations are made by a very senior level nuclear safety engineering manager. They are organized according to the five INPO/DOE safety indicators and the fourteen functional areas of safety discussed in Section 2.1.3. Inferences drawn from these observations are presented at the end of this section.

Jaslovské Bohunice - January 1992

Primary Areas of Observation

1. Operator Knowledge: Operators from two units (an older Model 230 and a newer Model 213) were quizzed through translators on the exact status of the plant and the meaning of various annunciators and indicators. The operators exhibited a high degree of awareness of system status, operational safety issues, and knowledge of plant activities (e.g. ongoing repair work, instrumentation and control calibration activities). Most impressive was their degree of knowledge about the likely impacts of impending major reconstruction outages to take place before 1995.

2. Operator Attitude: The control rooms observed were well staffed by attentive operators who continued with operational duties while discussing questions from visitors. The work surfaces in the control rooms were neat, orderly, and did not contain any non-work related materials. The control room environment was quiet and very professional. Detailed logbooks were kept in a fashion very typical to U.S. nuclear power plants. Unlike U.S. nuclear power plants the operators at Bohunice wear uniforms provided by the company and apparently laundered onsite.

   Discussions with the Deputy Director of Operations indicated the facility was embarking on major campaigns to upgrade operational and design safety. Detailed plans had been made on making 85 specific design changes, upgrading documentation to western standards, and improving the training of plant operators. The management exhibited a positive and pro-active attitude that clearly was reflected on the part of various other levels of the plant staff - from operators, to shift supervisors, to engineering support personnel.

3. Recordkeeping: As noted previously detailed control room logbooks were maintained. We additionally had the opportunity to look into the operating experience records. We found these to be comparable in quality, frequency of usage, types of items noted, and closeout at the end of each shift) to those maintained by U.S. nuclear power plants. We had no opportunity to determine the status of plant design documentation.

4. Personnel Errors and Injuries: There was only a limited basis for evaluating this indicator. The plant has an industrial safety program and apparently keeps statistics on injuries. We observed these posted in the locker room bulletin board.

5. Housekeeping and Safety Practices: The exterior of the plant was well maintained (by Eastern European standards). Roads and parking areas were in reasonably good repair. Grass and shrubbery were cut around the periphery of the plant. The exterior of buildings could use some cleaning. The interior of the plant (turbine hall, main reactor hall, control rooms, diesel enclosures) was neat and orderly. Fire hoses and

other fire fighting equipment were in place and in good repair. There were no accumulated piles of packing materials or other potential combustibles. Water and oil leaks were promptly cleaned up by plant maintenance staff. An extensive campaign of painting surfaces within the plant has been underway for several years.

We observed that the plant had a Lock and Tag procedure which included the use of clear plastic boxes that were attached on the top of main control board breaker control switches with a tag indicating the purpose of the lockout.

On the negative side, we observed that the painting had gotten a little out of hand. Examples in this area included: the valve stem and yoke of a mechanical spring loaded safety valve on a fluid vessel were painted together, raising the obvious question of whether the safety valve was operable. The threaded stem of several manual and motor operated valves were also painted, as were the grease and typical accumulated grit and dust. This gave us the first indication that work activities were not being scrutinized for possible safety impact. Not all work areas were completely restored to original status after completion of work activities. We observed temporary staging left in place at the site of a secondary plant valve that had been repaired (apparently) several months before. In the back of main control board panels wires from deactivated indicators (already removed) had not been removed and were left dangling in the air. These could make contact with active equipment or terminal strips and have unpredictable outcomes on plant operations.

Secondary Areas of Observation

1. Organization and Administration: The plant was organized in a fashion very similar to U.S. nuclear power plants (even including an independent nuclear safety engineering organization as required by INPO). The only major difference was the incorporation of a financial or economics department whose responsibility was in accounting and financial planning. In the U.S., this would typically be a utility headquarters function rather than a plant site function.

2. Operations: Based on very limited observation, the plants are operated in a very formal businesslike manner with written procedures, logbooks, reporting procedures, and clear lines of accountability and responsibility. Some members of the operations staff did comment to us that they recognized many areas were still felt to be informal compared to western standards. They stated they were seeking assistance in bringing these areas into line with western practices.

3. Maintenance: The material condition of the plant was comparable to plants of similar vintage in the United States. Some areas such as balance of plant insulation were better than in the United States. The only area of concern was the issue of whether the previously mentioned painting campaign was potentially impacting component operability. This raised questions regarding the management and safety review of

maintenance activities (a problem also found in the United States).

4. Training and Certification: Operators are trained and perform simulator exercises at the VÚJE Nuclear Power Plant Research Institute in Trnava. The simulator is of a vintage similar to U.S. nuclear plant simulators in the pre-TMI era (no 2-phase flow or loop draining or core uncovery models).

5. Auxiliary Systems: We had the opportunity to observe only the diesel and plant air systems on an unannounced basis. We observed no obvious problems based on a very limited observation.

6. Emergency Preparedness: No basis for evaluation.

7. Technical Support: This is an area that is under a very heavy workload with the impending modifications planned before 1995. Plant personnel are in the process of acquiring the capability to be fully self-sufficient. This is essential in view of the cut-off of assistance from the design institutes in the former Soviet Union. Despite the very heavy workload, plant personnel seemed positive and upbeat about the changes they were participating in making. Their only concern was about financing of upgrades.

8. Security/Safety Interface: Physical security at the site is provided by a contractor guard service (from Germany) and augmented by regular army troops from the Czech army stationed on-site. Physical access to the site is comparable to U.S. nuclear power plants and involves permission being granted by plant management, passage through metal detectors, and x-raying of hand baggage. Escorting of visitors is accomplished by plant personnel and accompanied by a plant security guard. (Again these features are very comparable to western practice.) Possession of cameras and the taking of photographs is strictly controlled and requires permission of plant management. Access to vital areas of the plant to allow fire fighting and emergency actions is not impeded by a large number of cardkey type doors. Access to the control room is gained via ringing a door buzzer. Control room personnel view the exterior corridor via a closed circuit TV before opening the door.

9. Experimental Activities: No basis for evaluation.

10. Facility Safety Review: There is an active operating experience review program seeking to determine root causes and lessons learned. We had no opportunity to look into the operations review committee structures or functioning.

11. Nuclear Criticality Review: No basis for evaluation.

12. Radiological Protection: Radiological protection practices appear to be comparable to those of U.S. nuclear facilities. We toured the main reactor hall after changing into lab coats and rubber slip-on boots. Portal monitors existed and were functioning at the exit of radiological control areas and at the exit of the plant site.

There is an active ALARA ("as low as reasonably achievable" - refers to efforts to limit radiation exposure) program in place with various targets for routine work activities as well as overhauls and refuelings. Status reports on ALARA goals/results are displayed in various locations in the plant. Again this is comparable with U.S. practice.

13. Personnel Protection: We observed a lock and tag procedure in place for high voltage breaker controls in the control room. We did not observe any glaring indications of occupational safety problems.

14. Fire Protection: There is a site fire department. Access roads to various plant buildings are in a good state of repair. Fire hoses and fire extinguishers are in place and apparently checked on a periodic basis. As a result of various safety studies (as well as a cable tunnel fire in 1989) plant management is keenly aware of the potential effects of plant fires.

Overall Evaluation

The management of the plant is aware that the Bohunice design does not meet generally accepted western nuclear safety standards (e.g., there is no containment and emergency cooling systems are limited). They have accepted this fact and are working to improve the physical design and the operational safety practices to bring them into compliance with western standards. The plant personnel at all levels recognize the situation they are in and the required teamwork and discipline they will need to turn the situation around.

<u>Kozloduy - May 1992</u>

Primary Areas of Observation

1. Operator Knowledge: The operators we talked with (in English) from Unit 4 appeared well trained in the operation of the plant and in the unique safety issues of VVER-440 Model 230's. They were fully aware of existing plant status and the meaning of various indicators we quizzed them about.

   One aspect we were unsure about was the degree to which the Unit 4 shift supervisor was typical of all other shift personnel. Upon entering the control room he gave us a lengthy dissertation on the operational safety features of the VVER-440 Model 230 in English (in a country in which most professionals learned Russian). He was obviously one of the most knowledgeable shift supervisors in the plant. We had no opportunity to talk with other operations personnel.

2. Operator Attitude: We found the control room we visited orderly and businesslike. There were no non-work related materials laying about. Logbooks were maintained and plant activities regularly entered. Operational aids (e.g., plant cooldown charts, reactivity balance charts) were readily observable near where they were used.

One area of concern we observed was that operations personnel displayed an attitude of defensiveness about their plant. They were reluctant to admit that obvious design areas of the plant were in need of upgrading. Examples included: open windows in the control room vs. western control room controlled environment and glass doors between the control room and the moisture separator reheater units. (The latter allow fires or projectiles in the turbine building to easily reach the control room.) This attitude was also observed when discussed with senior plant management. As an example the director of Units 5 and 6 commented that unlike the U.S. with it's TMI-2 accident, Bulgaria has never had a serious nuclear accident. This attitude was prevalent at various levels of plant personnel.

3. Recordkeeping Practices: Design documentation, test records, material specifications, and operating experience records at all levels are missing. All parties at the plant acknowledged this to be a major problem in determining existing safety levels, much less justifying continued operation to outside groups. It is also apparent that the plant is not reporting significant operational events to outside bodies. An example included the failure to report an apparent small LOCA which occurred when an instrument line welded to the discharge of a reactor coolant pump failed several years ago. This event was brought up in discussions with the Unit 5 and 6 Director.

4. Personnel Errors or Injuries: No basis for evaluation.

5. Housekeeping and Safety Practices: The material condition of the facility and site is very poor. The site perimeter is overgrown with weeds, bushes, and trees some of which straddle over perimeter fences (this is a physical security issue). All roadways and access roads within the plant site are in need of major repair because major potholes (some of which are 5-6 feet across and 1-2 feet deep) exist which preclude the rapid movement of emergency personnel. The interior of the plant is literally falling apart. Examples include: insulation is falling off of piping, vessels, pumps; contaminated water had flooded the Unit 1 radwaste treatment facility and water was observed to be leaking through cracks at the base of the building. Upwards of possibly 20% of all windows throughout the plant site are broken.

   Fire protection systems are in a total state of disrepair. CO2 systems in the diesel enclosures have missing pipe segments. Fire hoses are missing throughout the turbine hall (apparently due to pilferage by plant workers).

   We observed several immediate life safety hazards including: open/unbarricaded floor grates on the operating deck of the turbine hall, and leaking caustic chemicals in the chemistry addition area.

Secondary Areas of Observation:

1. Organization and Administration: The facility is organized with two deputy directors: one for Units 1-4 (the VVER-440s) and one for Units 5-6 (the VVER-1000's). The split probably makes good sense given the significantly different issues and required management focus for the plants. Management's concern with the older 440's is to keep them running despite the increasing degradation of the facility; the concern with the newer 1000's is to get them properly started. The facility organizations are similar to those found at U.S. nuclear power plants (e.g. organized along the lines of: operations, maintenance, engineering, etc.).

   Administration and payroll policies have resulted in significant turmoil among site workers. Operators on shift work were underpaid and significant morale problems existed several years ago. This caused a transfer to engineering of many of the shift workers. As a result of pressure from outside organizations, the salary of operators was then dramatically raised (apparently 400 - 500 %) over a very short time. One individual commented that Kozloduy operators now made more money than the Prime Minister of Bulgaria. This resulted in former operators leaving engineering positions in large numbers to go back to operations and created difficulties in providing staffing to perform safety evaluations of procedures and design modifications. The safety manager for Units 1-4 complained that he could not staff up a fire protection group because the operations manager for Units 5-6 could pay more money for skilled engineers. The inability to administer stable and consistent personnel and payroll policies is clearly contributing to organizational ineffectiveness.

2. Operations: Based on discussion with operators, there are not enough emergency operating procedures. The status is similar to what existed in the U.S. in the pre-TMI era. While control rooms are orderly run and well staffed, most communications are done in an informal manner and procedures are used as guidance documents rather than rules to be explicitly followed. Shift supervisors do not understand the concept of walk-around surveillances.

3. Maintenance: The material condition of the facility is in a very bad state of disrepair. As noted above, there is widespread evidence that equipment is falling apart on an accelerating basis. We found that there were very few maintenance procedures for such basic tasks as pump or turbine overhauls. While we were touring the site, we had opportunity to visit with a team of personnel from WANO/INPO who were helping to establish a more comprehensive maintenance program and outage planning process. Hopefully this area will be on an improving trend in the future.

4. Training and Certification: Based on discussions with the operators, all operators have the equivalent of a B.S. degree in engineering. Most were trained in the former Soviet Union. Very few have had the benefit of simulator training - even on crude simulators.

5. Auxiliary Systems: Based on a relatively short walk around tour of the safety related systems, we found major deficiencies in the upkeep of these systems. Examples included: insulation falling off the emergency condensate storage tank (a crucial source of backup cooling water; the lack of insulation means that there is a potential for freezing in winter time), diesel generator enclosures with inoperable fire doors between redundant diesels (hence a fire could cause the loss of emergency backup power), deactivated CO_2 systems above the diesels, and boric acid leakage around emergency cooling systems. The diesel fire protection issue was compounded by fuel oil leakage that was not cleaned up.

6. Emergency Preparedness: We had little basis for evaluating this issue other than to note that the telecommunications capability between Kozloduy and Sofia (much less the outside world) is inadequate and highly unreliable. In case of a site emergency, it appears unlikely that significant guidance and support can be provided from the outside.

7. Technical Support: Within the engineering organization there is a nuclear safety engineering organization which also is responsible for fire safety. The organization is undermanned, has excessive work requests from other groups, and has payroll inequity problems (noted above) which contribute to a major morale problem. The individuals in this organization seem more preoccupied with defending the status quo of the facility to outside organizations than in constructively evaluating possible upgrades.

8. Security/Safety Interface: Physical security at Kozloduy is very lax by western standards. We observed a truck carrying building materials enter the site with only a cursory check of the driver's credentials and no search for contraband on the truck. Entrance to the plant site is by written permission of plant management. At the entry points security guards merely check credentials and camera passes. There is no X-ray of hand baggage or metal detectors.

9. Experimental Activities: No basis for evaluation.

10. Facility Safety Review: These activities are carried out by the nuclear safety engineering organization. We had limited opportunity to evaluate the functioning of this organization. We did find indications that they were not reporting all nuclear incidents to the IAEA Incident Reporting System. The most significant event in question was a small LOCA that was successfully mitigated using plant emergency systems.

11. Nuclear Criticality Safety: No basis for evaluation.

12. Radiological Protection: The radiation protection program at Kozloduy is very lax. Upon entry to the site we observed large numbers of personnel passing through portal monitors without stopping to be counted. Upon asking a deputy director if it was not required to measure all personnel upon exiting he stated: "Yes it is required. But

there are worse problems at Kozloduy. Besides those people don't work in contaminated areas." This response told us that the plant has requirements, workers have chosen not to comply, and that plant management is aware of the non-compliance and have chosen to rationalize away the problem rather than deal with it.

While touring the site, we observed a number of radiological safety problems including: excessive boric acid leakage in the emergency cooling system areas, a 600 gallon per day leak from the Unit 1 spent fuel storage pool (which had subsequently flooded the Unit 1 radwaste building) and the resultant radwaste leakage to the soil through foundation cracks in the radwaste building.
We were not able to obtain any information on the extent of the Kozloduy ALARA program.

13. Personnel Protection: We had very limited opportunity to evaluate this area. We did observe an open/unbarricaded floor grating section on the operating deck of the turbine hall. Anyone falling through this open section would fall possibly 75 feet to the sub-basement level.

14. Fire Protection: There is no significant fire protection program at the plant. Original design features (CO2 systems) have been deactivated. Fire hoses are generally missing as a result of pilferage by plant personnel. We did find a few fire hoses locked in a cabinet in the Unit 4 control room. These hoses did not appear to be functional. There have been no fire hazards assessments nor development of fire fighting procedures at the plant. Given the poor condition of access roads around the site, it is difficult to envision how fire fighting equipment could be moved to a particular location quickly.

Overall Evaluation

The management of Kozloduy does not have effective control of facility safety. There are significant problems in the areas of radiological protection, fire protection, technical support, maintenance, and a number of facets of operations. Equipment conditions are in a deteriorating state. Personnel at several levels throughout the plant organization have an indifferent attitude. Motivation to improve the situation is low. We would expect to see the deterioration of power generating equipment begin to effect power generation statistics (e.g., capacity factors) within the next several years unless major improvements are made.

Plant Comparison

The preceding discussion shows that Bohunice scores clearly better in three of the five INPO/DOE indicators (see Section 2.1.3 for the list of indicators): operator attitude, record keeping, and housekeeping/safety practices. Both Kozloduy and Bohunice score reasonably well in the area of operator knowledge; there is insufficient information available to rate the plants' performances in the area of personnel errors and injuries. (Note that human error-caused outages are recorded in the IAEA data base, but statistics for these have not been developed for this report.)

In terms of the fourteen key functional areas considered by INPO and DOE, Bohunice again is clearly better in almost all of the fourteen. Key differences are observed in organization and administration, operations, maintenance, auxiliary systems, security, facility safety review, radiological protection, personnel protection, and fire protection. Emergency preparedness is not included on this list, due to the limited amount of information gathered on this subject. However, the lack of reliable communications to the outside from Kozloduy appears to be a critical safety problem.

To compare the basic organizational processes at the two plants, it is useful to employ the four basic organizational factors identified by Ref. 6 and briefly discussed in Section 2.1.2: organizational focus, communication, organizational learning, and external factors.

Organizational Focus

Both plants are clearly focused on energy production as the primary goal. However, based upon the attitudes expressed by plant managers during interviews, Bohunice appears to place a higher priority on safety than does Kozloduy. This evaluation is also supported by Bohunice's better attitude towards safety improvement (proactive and learning oriented versus defensive), initiation of major safety-related campaigns, better bookkeeping, better facility condition, better programs for organizational learning, better security, better radiological protection, and better fire protection. Thus, not only does the Bohunice organization have a better attitude towards safety (as compared with Kozloduy), it also apparently has provided resources to enable safety-related processes.

Communication

As discussed in Section 2.1.2, the factor "communication" relates specifically to the communication of objectives throughout an organization. During a short site visit, the effectiveness of communication cannot be assessed directly. Nevertheless, the available information allows the inference that both plants have effective communication. In both cases, the operating staffs' attitudes, the effectiveness of safety processes, and the facility conditions clearly reflect the attitudes of management towards safety. It just happens that the attitudes of the Bohunice and Kozloduy management differ.

Organizational Learning

Given the apparently stronger emphasis of the Bohunice organization on safety, it is not surprising that Bohunice appears to have a stronger capability to learn from mistakes (both its own and others) than does Kozloduy. Bohunice has an active root cause analysis program (see also Section 2.1.4), good record keeping, and a good attitude towards learning from the experience of others. The organization also apparently has sufficient resources to implement learning programs. The evidence from Kozloduy suggests a much poorer attitude towards learning and a lack of necessary resources (e.g., information provided by record keeping) to support programs implementing any lessons learned.

External Factors

No observations were made in this area during the site visits. It is interesting to note, however, that based upon personal observations and discussions with others, the head of the Czechoslovakian regulatory agency is both knowledgeable and very seriously committed to safety. (Prior to the recent political changes in Eastern Europe, he was once forced to leave the country because of his questioning of safety practices at Czech plants.) The head of the Bulgarian regulatory agency, on the other hand, appears to be more committed to assuring that energy production continues (versus safety). All interactions with peers from outside Bulgaria seem to be initiated from a standpoint that Kozloduy must continue to operate because of power needs.

3. Concluding Remarks

This chapter summarizes the key lessons learned in the project, the limitations of the work important in interpreting the significance of these lessons, a number of improvements that could strengthen the results, and a number of longer term issues whose resolution is important for future assessments of international reactor safety.

3.1 Lessons Learned

A number of interesting and useful lessons have been learned through the development and performance of this project. In a general sense, it has been discovered that much can be learned by analyzing and interpreting published reports of nuclear power plant operational data. Subject to a number of important qualifiers, plant availability measures are somewhat related to plant safety. For example, poor plant availability may be an indicator of lax maintenance practices. By examining the causes of plant outages, inferences may be made about maintenance practices at the plant.

Other lessons learned relate to the relative usefulness of anecdotal information in conjunction with published statistics. Specifically, it was learned that the joint use of anecdotal information and statistics provides a more detailed and comprehensive picture of plant safety than either one alone. This is, of course, particularly true when both data sources tend to corroborate one another. Anecdotal information provides important contextual background and impressions, but lacks a rigorous statistical framework. Statistical information is often collected and presented in a rigorous fashion, but may be misinterpreted if the overall context of plant operations is not well understood. By combining the two sources of data, the strengths of each are utilized. It was also learned that while anecdotal information collected in any fashion can be useful, the development of improved guidelines for collecting this information would be helpful in making the data collection more complete and systematic. Western nuclear experts who have an opportunity to visit foreign power plants and debriefers of those nuclear experts would both likely benefit from such a set of guidelines. This matter is further discussed in the following section.

In terms of the plants which were analyzed in this study, it was learned that the Bohunice plant in Czechoslovakia clearly appears to be a safer plant than the Kozloduy plant in Bulgaria. This conclusion is borne out by both the analysis of statistical data and by direct observation and anecdotal information. It should be pointed out, however, that the anecdotal information gives a stronger picture of the differences between the two plants than does the statistical information. This in part underscores the importance of interpreting the statistical information in the context of the actual plant environment or culture, and in part suggests that the poor practices and conditions which are present at the Kozloduy plant today may not be fully manifested in the operating statistics of the plant until some future time.

3.2 Analysis Limitations

As noted at the beginning of this report, this project represents an initial, limited-scope demonstration of how available information can be used to assess the safety of Eastern European reactors. It therefore has a number of limitations that should be recognized when interpreting results.

Clearly, a significant limitation of the work is that it focused on a limited number of plants in only two organizations. A review of data from more plants would not only provide a more complete picture of Eastern European reactor safety, it would also provide a more accurate picture of the relative frequency of undesired events (e.g., unplanned outages). This, in turn, would allow a better assessment of the expected rate of events, which is useful when trying to determine if events are being properly reported by an organization.

A second limitation is that only a subset of the data gathered during the project was employed. Additional information can be extracted from the IAEA data base with additional effort. For example, unplanned outages can be classified as manifestations of particular organizational problems e.g., poor maintenance, but this requires the analyst to draw additional inferences from the data base (rather than simply manipulate precompiled statistics). As another example, anecdotal information from utility and regulator reports were not used very much in the comparison of Bohunice and Kozloduy; Section 2.1.4 shows that this information is potentially useful, especially if it is available for both plants. As a final example, the analysis results are largely based on published data for full outages; data from partial outages (during which the plant is producing power at a reduced level) are not always incorporated.

A third limitation is that key data directly relevant to safety (e.g., availability of standby safety systems) are apparently unavailable. As discussed in Section 3.1, operational data can be used to draw safety-related inferences, but direct evidence of the ability of a plant to withstand an accident is a clearly superior source of information.

A fourth limitation is that the statistical analysis of the data is limited. Issues such as the variance in, correlation between, and time-dependent behavior of indicators are not addressed. A more comprehensive analysis would lead to a more detailed representation of the importance of the various issues raised.

3.3 Potential Improvements

From the preceding discussion, it can be seen that a number of improvements can be made to the data gathering and analysis processes. These improvements are as follows:

- Gather data from more Eastern European plants

  This entails collection of published statistical data (a relatively easy task) and of additional anecdotal information (a more difficult one).

It may be necessary to interview knowledgeable people who have visited other sites during formal and informal inspections, and to obtain trip reports for these inspections. As discussed in Section 3.1, anecdotal information is needed to interpret available statistics (e.g., to indicate underlying causes of observed problems).

- Gather and employ more data for the plants analyzed

  Regarding statistical data, this requires either gaining access to a comprehensive, computerized data base, or the creation of such a data base. (Data manipulations and "what-if?" calculations were done within a simple spreadsheet and required manual input; this consumed a considerable amount of time and limited our ability to test hypotheses linking different data.) Regarding anecdotal information, this requires the collection and review of additional reports and papers of the Kozloduy and Bohunice plants, and the integration of this material into the analysis.

- Develop a causal-based taxonomy for outages/events

  This is needed to support the previous two improvements. It involves the development of a taxonomy that will highlight weaknesses in organizational processes and functions, and rules for interpreting available data in terms of this taxonomy. It is anticipated that a simple taxonomy can be developed using available information (e.g., SALP, the INPO/DOE inspection guidelines, and the results of NRC research on organizational factors). A more detailed and fundamental taxonomy requires more long-term work, as described in the following section.

- Perform a more comprehensive analysis of statistical data

  As discussed in Section 3.2, this involves analyses to assess uncertainties in indicator statistics, associations between indicators, and indicator trends.

3.4 Long-Term Issues

In the course of this work, two issues have been identified which cannot be resolved using available knowledge or data. These issues indicate areas where additional research is needed.

The first issue concerns the structure and content of issue/problem area/question lists used formally or informally by personnel performing plant inspections and by other personnel debriefing these inspectors. As shown by the discussions on the SALP rating process and on the INPO/DOE facility inspection guidelines, various lists are being used by different organizations. These lists, have been developed empirically based on past experience concerning what is important in a nuclear facility, and tend to be oriented along the lines of key functional areas (e.g., management, maintenance, radiological protection).

The problem with these lists is that they do not directly reflect fundamental organizational processes common to the functional areas (e.g., organizational learning). As a result, the lists do not explicitly address issues that cross functional area boundaries. A second result is that the lists reflect the conventional wisdom and "best practices" of one country/culture, and may not recognize that a given problem can be successfully handled in many different ways. Research on the organizational processes relevant to plant safety could conceivably lead to the development of improved lists of questions for inspectors and debriefers. The NRC-sponsored work discussed in Section 2.1.2 provides initial steps in this direction, but has not yet developed results that can be directly used in projects such as this.

A second, related issue concerns the development of leading safety indicators to assist the evaluation of a given plant's performance and safety level. Currently used indicators tend to focus on observable hardware-level effects (e.g., number of automatic scrams) rather than underlying causes. Even the recently proposed indicators mentioned in Section 2.1.2 tend to treat organizational factors indirectly.

As in the case of the issue/problem area/question lists, it is clearly desirable to develop indicators based on knowledge of fundamental organizational processes. Here too, there is a danger of evaluating plant performance from the standpoint of context-dependent best practices if organizational principles are not addressed. The development of an improved set of leading indicators would greatly aid analysts attempting to evaluate plant safety from afar. It could also provide additional help to personnel visiting a plant.

In summary, organizational issues arise in the areas of data collection (structuring query lists) and data evaluation (assessing the level of plant performance and safety through key indicators). Research is needed to address these issues; the work reported in Ref. 6, Ref. 1, and Ref. 20 (which reports on internationally-sponsored work performed at M.I.T.) provide useful starts in this direction.

In closing, it can be remarked that among the many current and potential applications of the ideas discussed in this report is the use of statistical and anecdotal information to improve the DOE's ability to monitor and predict the course of nuclear accidents in Eastern Europe should they occur. Whether monitored formally in a dedicated facility like the USNRC's Emergency Operation Center or in some other way, the DOE undoubtedly wants to be in the best possible position to anticipate the course and outcome of any future nuclear accidents in foreign countries. Although additional work must be done to refine and expand the work performed on this exploratory project, early indications are that the information used and the framework developed for organizing the information could provide important input to such a monitoring program.

References

1. J. Wreathall, et al., "A Framework and Method for the Amalgamation of Performance Indicators at Nuclear Power Plants," prepared for the USNRC by SAIC and the University of Maryland, April 15, 1992.

2. Memo for Patrick Baranowsky (Chief of Trends and Patterns Analysis Branch, Division of Safety Programs, Office for Analysis and Evaluation of Operational Data) from Thomas R. Wolf (Senior Reactor Engineer, Performance Indicator Section, AEOD/DSP/TPAB), July 30, 1992.

3. USNRC Office for Analysis and Evaluation of Operational Data, "Performance Indicators for Operating Commercial Nuclear Power Reactors, Report for Third Quarter 1991, Data through September 1991, Parts I and II," 1991.

4. USNRC Office for Analysis and Evaluation of Operational Data, "Performance Indicators for Operating Commercial Nuclear Power Reactors, Report for Fourth Quarter 1991, Data through December 1991, Draft Adjustments for Operational Cycle, Parts I and II," 1992.

5. USNRC Region I, "Initial Systematic Assessment of Licensee Performance, Report Nos. 50-387/90-99; 50-388/90-99, Pennsylvania Power & Light Company, Susquehanna Steam Electric Station Units 1 and 2," June 3, 1992.

6. T. Ryan, "Organizational Factors Research Lessons Learned and Findings," informal report, USNRC Human Factors Branch, Office of Nuclear Regulatory Research, September 1991.

7. A. Marcus, et al., "Organization and Safety in Nuclear Power Plants," NUREG/CR-5437, May 1990.

8. J. Wreathall, et al., "The Development and Evaluation of Programmatic Performance Indicators Associated with Maintenance at Nuclear Power Plants," NUREG/CR-5436, May 1990.

9. J. Montgomery, et al., "Team Interacting Skills Evaluation Criteria for Nuclear Power Plant Control Room Crews," PNL-7250, Battelle Pacific Northwest Laboratories, October 1990.

10. EG&G Idaho, Inc., "Department of Energy Facility Surveillance: A Guide for Surveillance Program Planning and Implementation."

11 Nucleonics Week, McGraw-Hill Publications, Vol. 29 No.23, June 9, 1988.

12. Operating Experience with Nuclear Power Stations in Member States, International Atomic Energy Agency, Vienna, 1991.

13. World Nuclear Performance, McGraw-Hill Publications, New York.

14. Nuclear Engineering International-World Nuclear Industry Handbook, Reed Business Publishing Group, United Kingdom.

15. Inside NRC, McGraw-Hill Publications, New York.

16. Nucleonics Week, McGraw-Hill Publications, New York.

17. J. Suchomel, "Analyses of Operational Events at Czechoslavak Nuclear Power Plants," presented at the VUJE/ANL/IAEA Workshop on Safety Review/Inspection in NPP Operation, Training Centre, Nuclear Power Plant Research Institute, Trnava, Czechoslovakia, January 13-17, 1992.

18. Memo for H.S. Blackman (Manager, Risk Assessment and Applied Mathematics Group, EG&G Idaho) from J. H. Bickel (Manager, Safety and Risk Evaluation Unit, EG&G Idaho), January 24, 1992.

19. Memo for H.S. Blackman (Manager, Risk Assessment and Applied Mathematics Group, EG&G Idaho) from J. H. Bickel (Manager, Safety and Risk Evaluation Unit, EG&G Idaho), June 18, 1992.

20. J. Carroll, C. Perin, and A. Marcus, "Organization and Management of Nuclear Power Plants: Excerpts from the Progress Report of the MIT International Program for Enhanced Nuclear Power Plant Safety," June 1992.

APPENDIX I: OPERATIONAL DATA

This appendix presents the collected operational data for the Eastern European plants which are evaluated in this report. The data is presented both in tabular form and graphically. Tables I-1 through I-5 show the historical data for each of the plants in question. Figures I-1 through I-18 present nine of the operational data categories for the Bohunice and Kozloduy plants.

Table ?C-1. Bohunice 1 Performance indicators since 1983 (Fef. &1).

Year	Max. Net Capacity, MW(e)	Energy produced, GW(e)h	Load Factor	Energy Availability Factor	# of full unplanned outages	# of partial unplanned outages	Equipment related outages	Refueling duration (hr)	Time lost to planned maint. (hr)	Time lost to unplanned maint. (hr)	# of leak events
1983	398	2754.1	0.790	0.789	6	0	6	1006	171	248.4	6
1984	408	3229.6	0.901	0.898	1	2	3	0	281	32	1 0
1985	408	2445.7	0.684	0.720	1	1	2	1922	332	21	1
1986	408	2486.0	0.696	0.705	3	1	4	988	425	381	4
1987	408	2701.7	0.756	0.773	1	4	5	982	39	229	4
1988	408	2061.6	0.575	0.564	5	0	5	2995	0	518	5
1989	408	2846.6	0.796	0.801	3	1	4	1041	265	318	3
1990	408	2776.5	0.777	0.800	2	3	5	1064	0	242	3

Table ?C-2. Bohunice 2 Performance indicators since 1983 (Ref. &1)

Year	Max. Net Capacity, MW(e)	Energy produced, GW(e)h	Load Factor	Energy Availability Factor	# of full unplanned outages	# of partial unplanned outages	Equipment related outages	Refueling duration (hr)	Time lost to planned maint. (hr)	Time lost to unplanned maint. (hr)	# of leak events
1983	398	2946.6	0.845	0.849	1	0	1	919	240.2	36.6	3
1984	398	2782.6	0.796	0.762	0	1	1	1054	421	0	0
1985	408	2444.7	0.684	0.723	0	2	1	1911	183	0	0
1986	408	2833.0	0.793	0.803	1	2	3	953	240	85	3
1987	408	2902.4	0.812	0.829	0	1	1	757	154	0	1
1988	408	2947.5	0.822	0.840	3	4	7	966	0	77	6
1989	408	2637.8	0.738	0.736	0	8	8	1888	97	0	4
1990	408	2683.0	0.751	0.761	3	3	6	1093	343	400	4

Table ?C-3. Kozloduy 1 Performance indicators since 1982 (Ref. &1)

Year	Max. Net Capacity, MW(e)	Energy produced, GW(e)h	Load Factor	Energy Availability Factor	# of full unplanned outages	# of partial unplanned outages	Equipment related outages	Refueling duration (hr)	Time lost to planned maint. (hr)	Time lost to unplanned maint. (hr)	# of leak events
1982	408	2685.6	0.751	0.833	0	0	0	1272	177	0	0
1983	408	2819.5	0.789	0.907	0	0	0	754	58.5	0	10
1984	408	2751.8	0.768	0.829	0	1	1	705	63	0	0
1985	408	2991.4	0.837	0.918	1	0	1	584	43	73	1
1986	408	2532.2	0.708	0.765	3	2	3	1842	0	110	2
1987	408	2959.5	0.828	0.985	0	0	0	674	93	0	2
1988	408	2837.0	0.792	0.877	1	8	9	696	0	6	4
1989	408	2159.5	0.604	0.666	1	6	7	2728	0	4	1
1990	408	2524.0	0.706	0.808	3	5	7	999	0	13	5

Table ?C-4. Kozloduy 2 Performance indicators since 1982 (Ref. &1)

Year	Max. Net Capacity, MW(e)	Energy produced, GW(e)h	Load Factor	Energy Availability Factor	# of full unplanned outages	# of partial unplanned outages	Equipment related outages	Refueling duration (hr)	Time lost to planned maint. (hr)	Time lost to unplanned maint. (hr)	# of leak events
1982	408	2789.2	0.780	0.897	0	0	0	850	0	0	0
1983	408	2946.9	0.825	0.916	0	0	0	732.7	0	0	0
1984	408	2653.2	0.740	0.823	1	1	2	1292	0	24	0
1985	408	2939.6	0.822	0.895	3	0	3	513	61	350	2
1986	408	2776.9	0.777	0.849	1	2	2	1043	94	112	1
1987	408	2634.5	0.737	0.849	4	0	4	843	193	286	3
1988	408	1964.9	0.548	0.744	3	3	6	1760	0	407	3
1989	408	2694.6	0.754	0.845	0	8	7	801	880	0	1
1990	408	2430.3	0.680	0.793	5	4	6	1192	0	134	6

Table ?C-5. Kozloduy 3 Performance indicators since 1982 (Ref. &1)

Year	Max. Net Capacity, MW(e)	Energy produced, GW(e)h	Load Factor	Energy Availability Factor	# of full unplanned outages	# of partial unplanned outages	Equipment related outages	Refueling duration (hr)	Time lost to planned maint. (hr)	Time lost to unplanned maint. (hr)	# of leak events
1982	408	2652.3	0.742	0.885	0	0	0	871.8	140	0	0
1983	408	2748.9	0.769	0.836	1	0	1	1330.7	38.5	66.9	0
1984	408	3135.4	0.875	0.934	0	0	0	576	0	0	0
1985	408	3204.8	0.897	0.942	0	0	0	505	0	0	0
1986	408	2688.1	0.752	0.774	0	3	2	580	0	0	2
1987	408	2752.6	0.770	0.824	4	0	3	1359	0	161	1
1988	408	3119.0	0.870	0.923	1	5	6	566	0	37	3
1989	408	2429.0	0.680	0.726	1	4	5	2232	0	8	1
1990	408	2606.9	0.729	0.782	5	7	7	1019	0	6	7

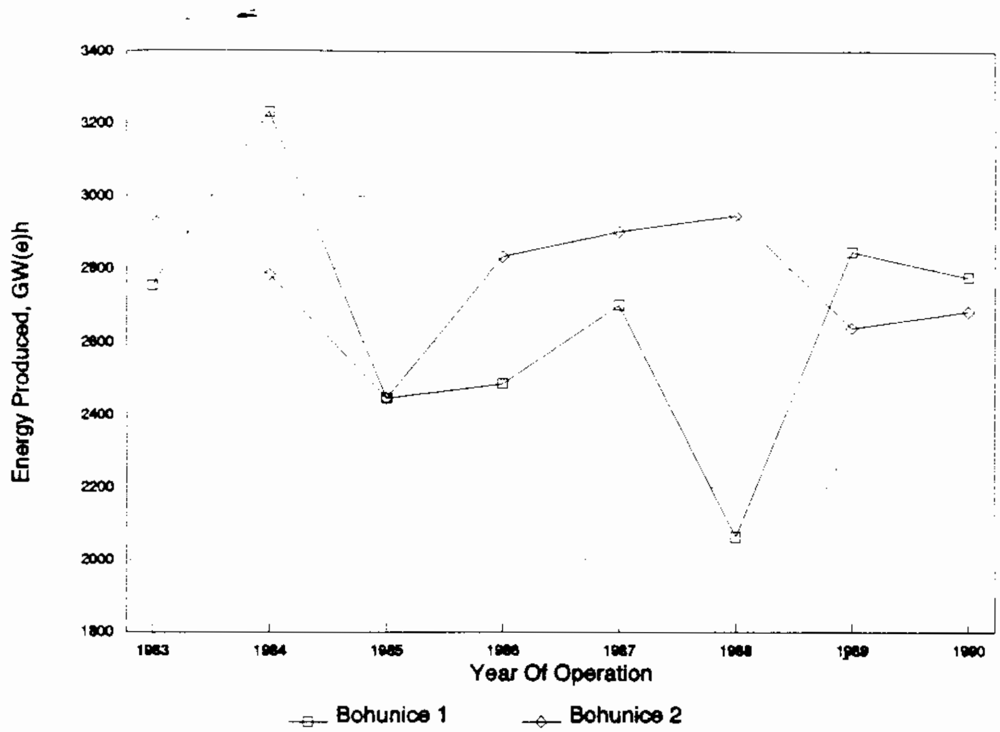

Figure I-1. Bohunice energy production operational data.

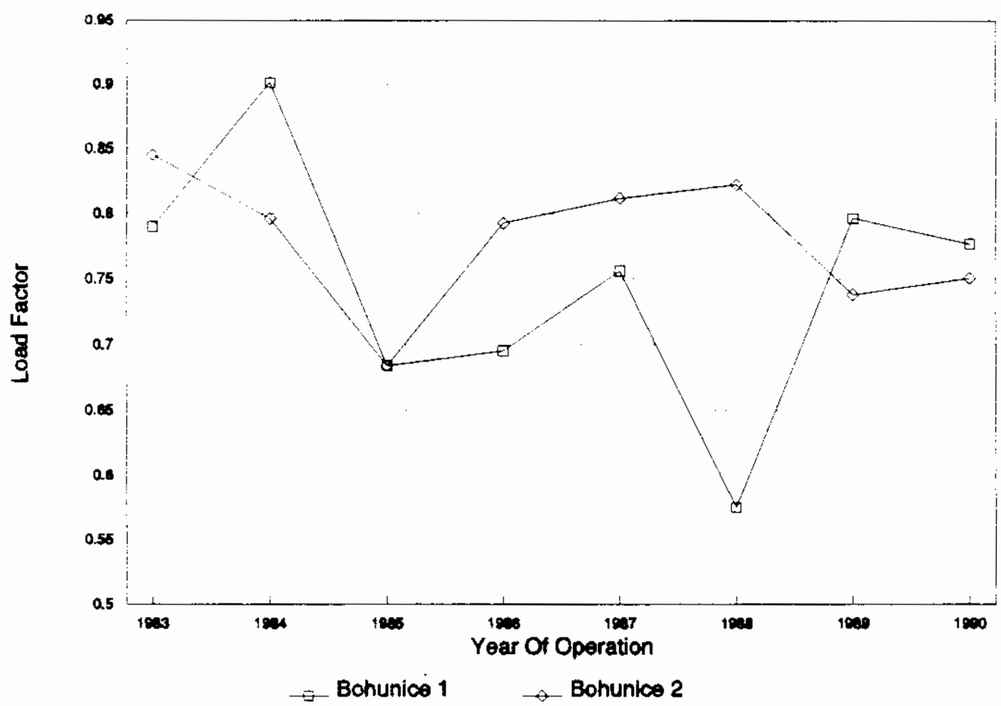

Figure I-2. Bohunice load factors.

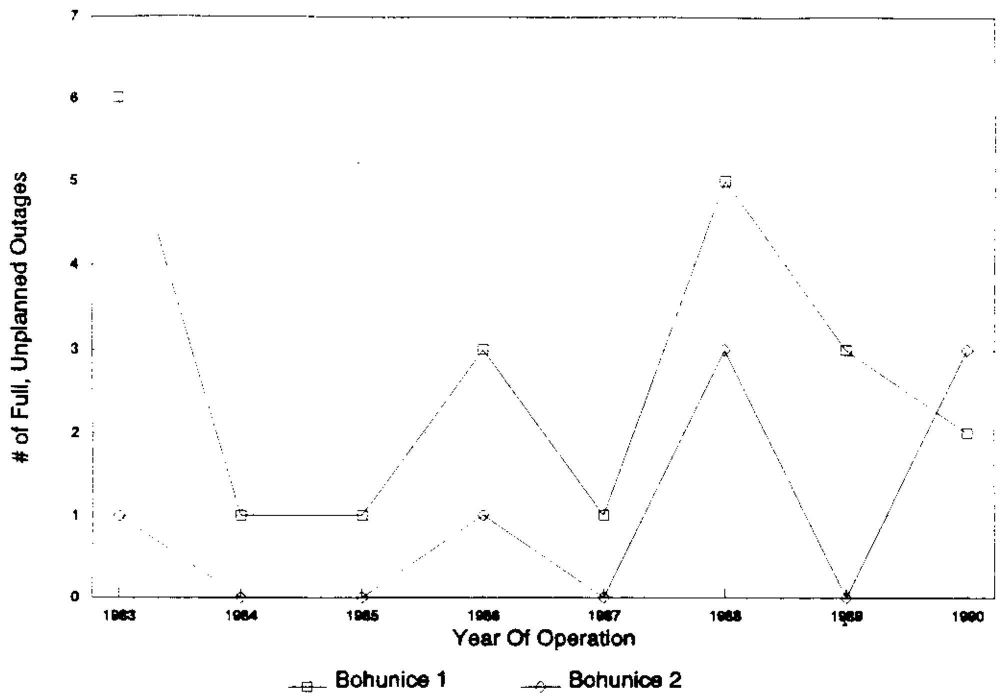

Figure I-3. Bohunice full unplanned outages.

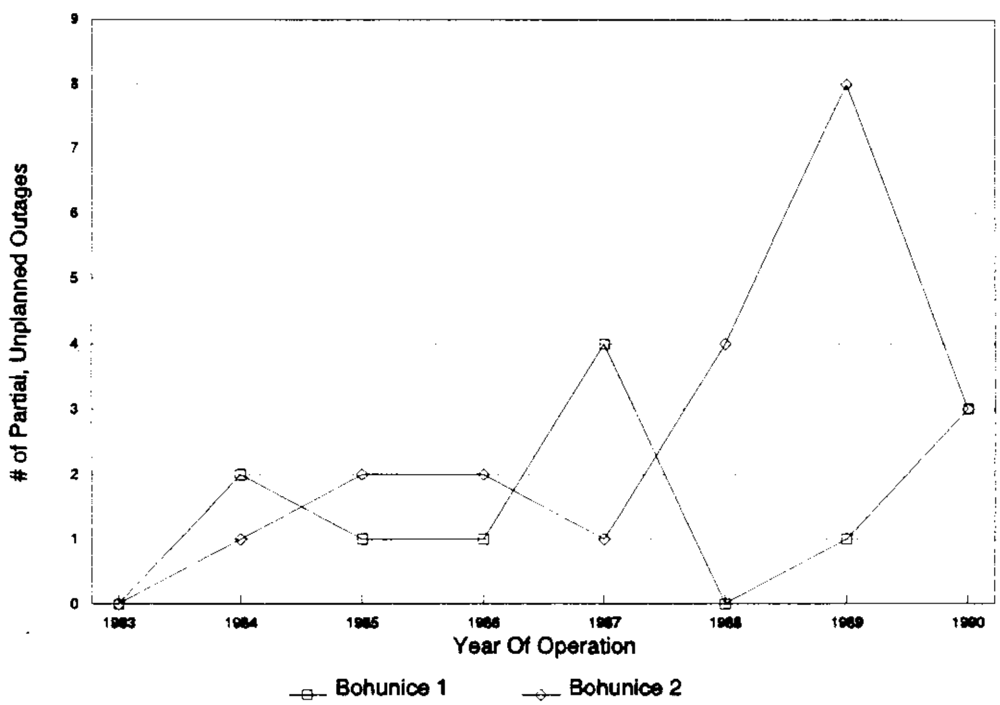

Figure I-4. Bohunice partial unplanned outages.

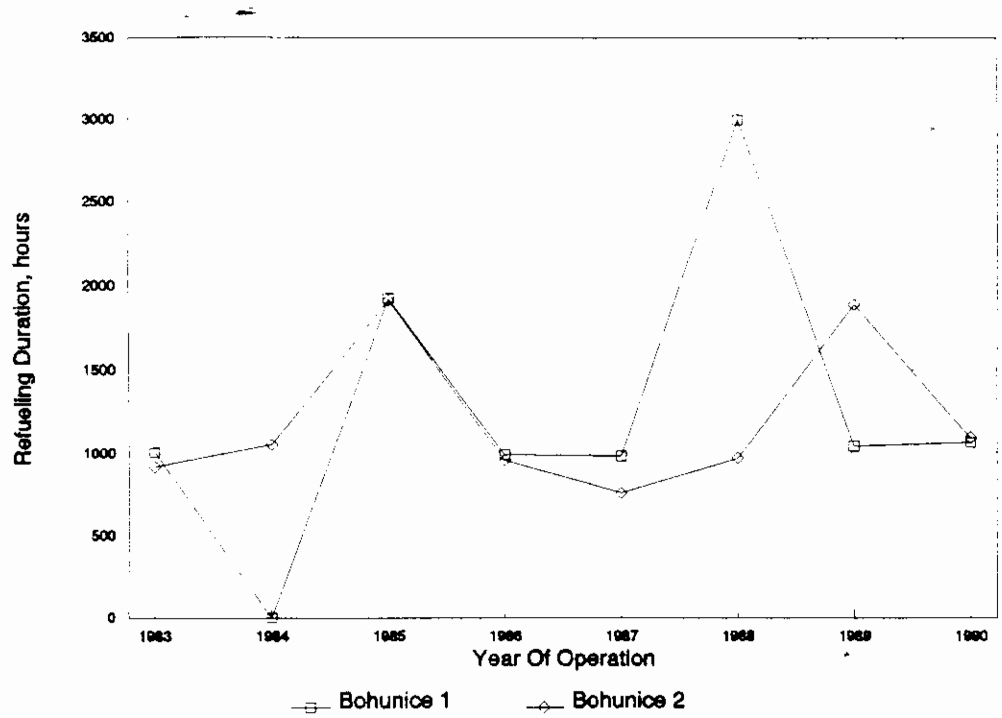

Figure I-5. Bohunice refueling durations.

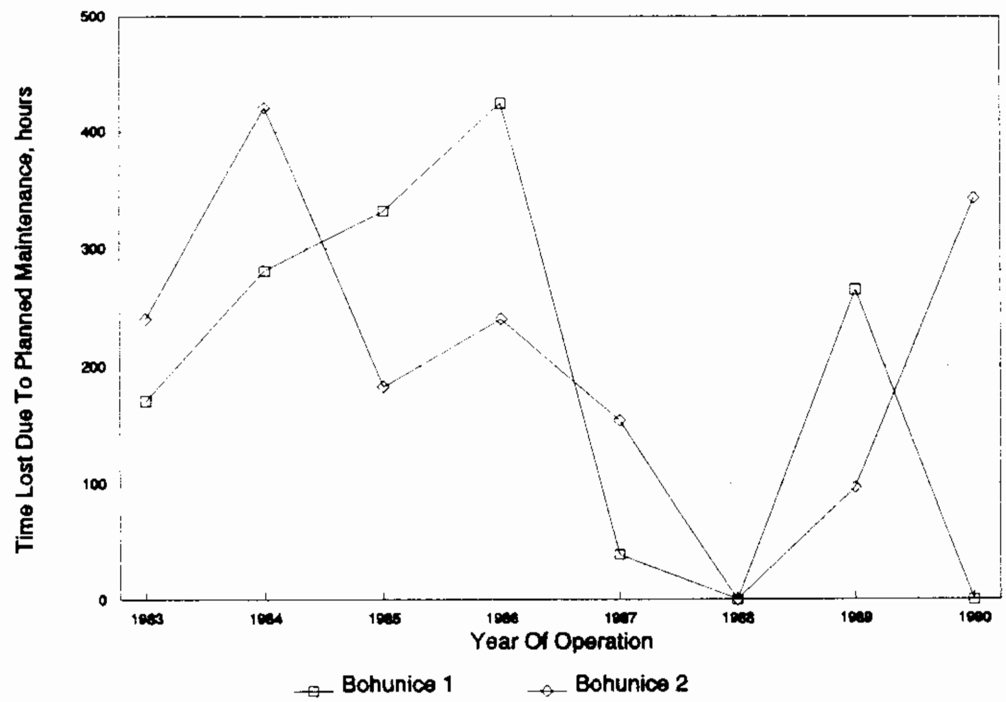

Figure I-6. Bohunice planned maintenance.

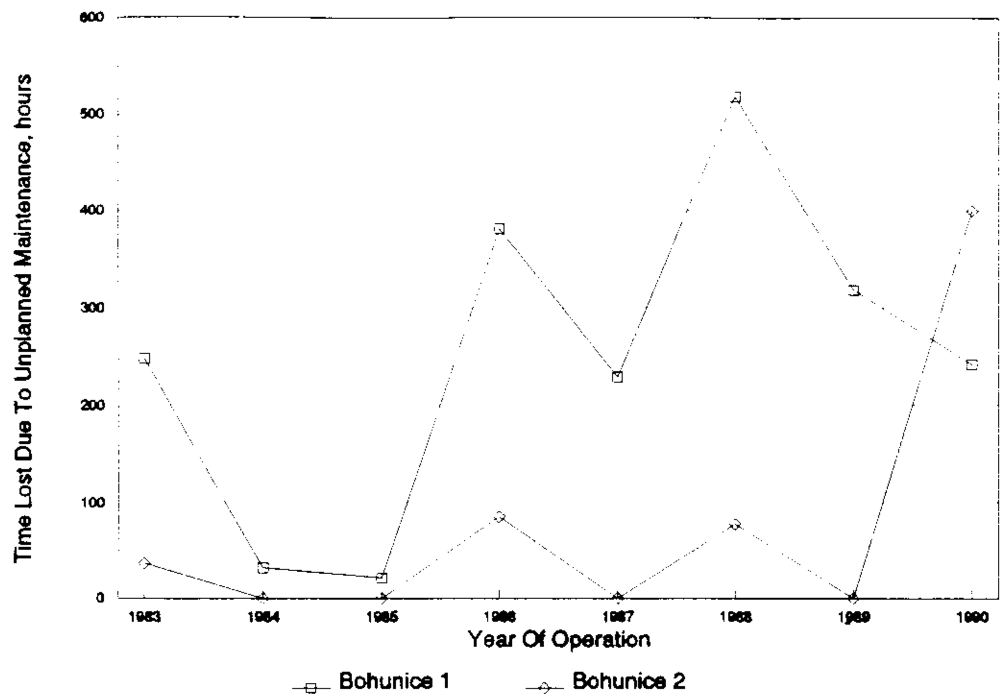

Figure I-7. Bohunice unplanned maintenance.

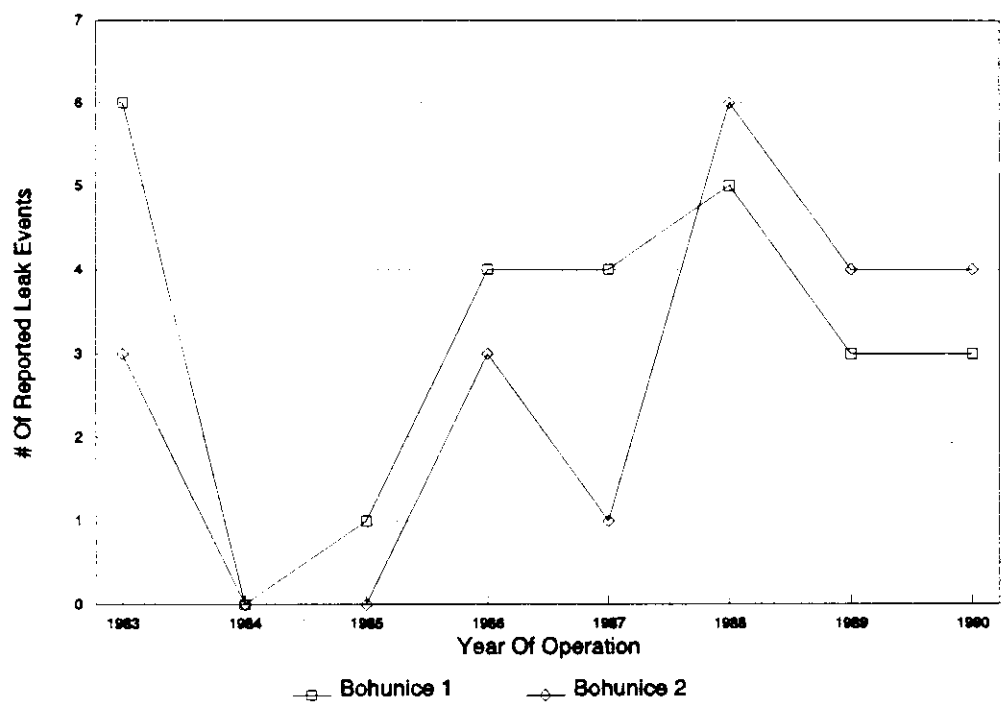

Figure I-8. Bohunice reported leak events.

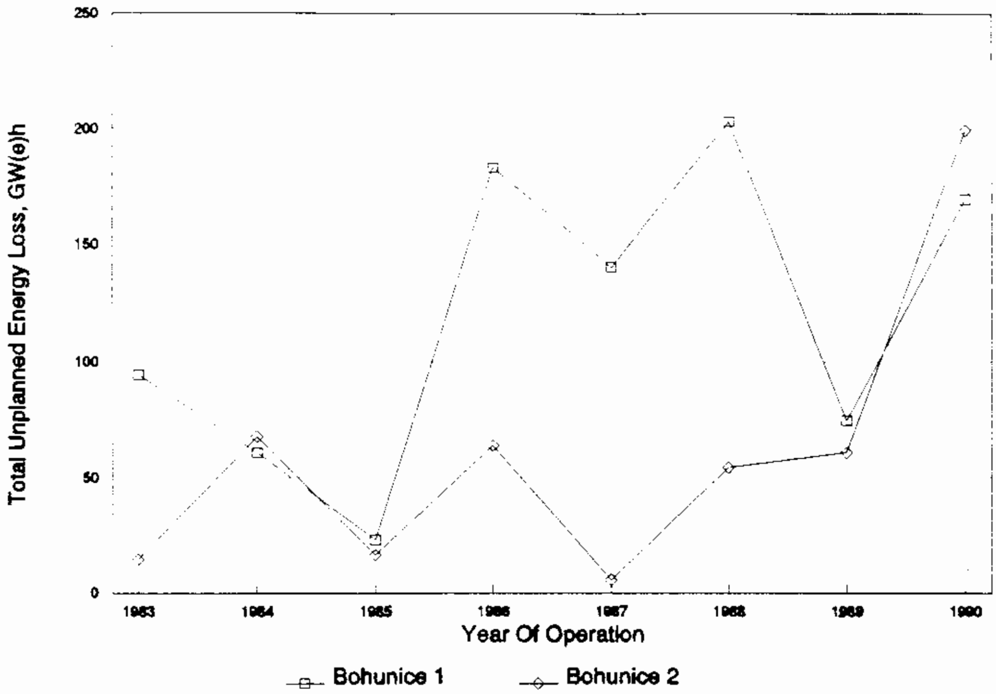

Figure I-9. Bohunice unplanned energy losses.

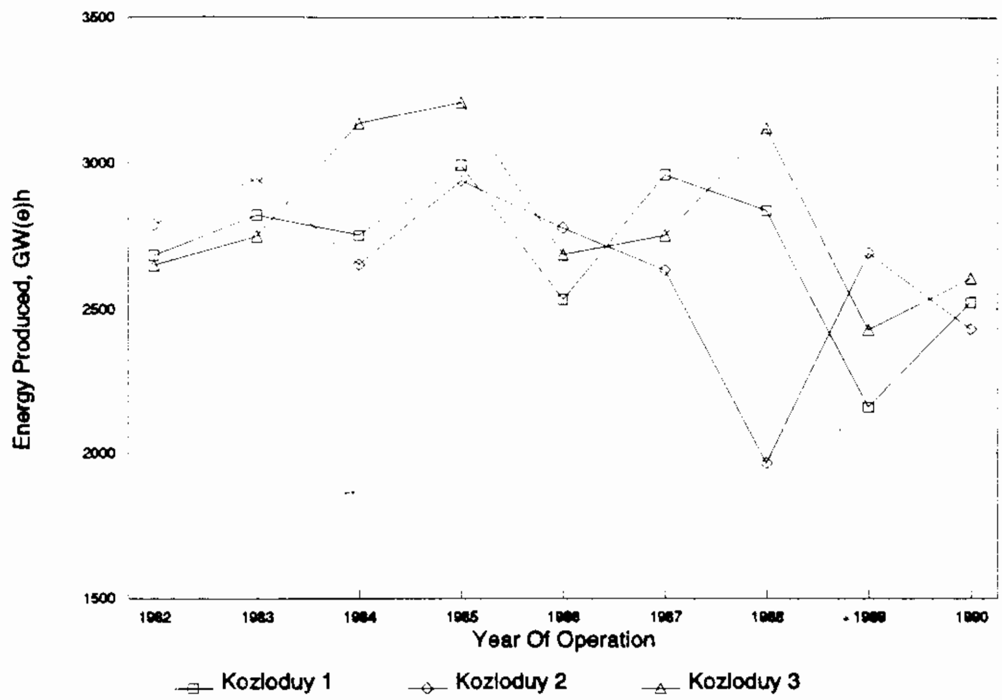

Figure I-10. Kozloduy energy production operational data.

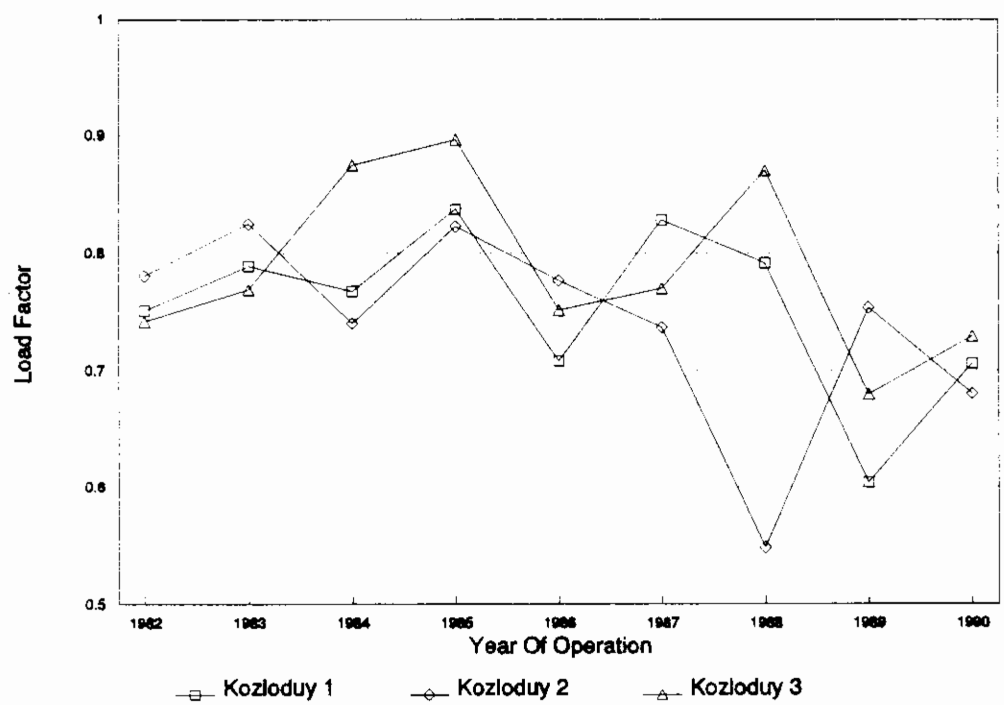

Figure I-11. Kozloduy load factors.

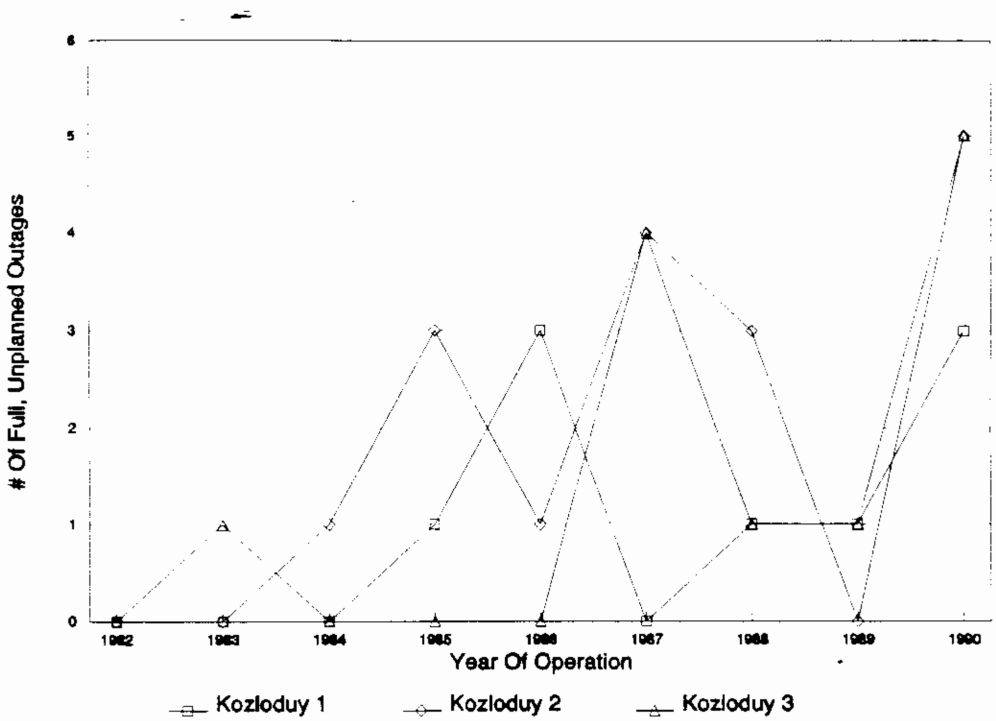

Figure I-12. Kozloduy full unplanned outages.

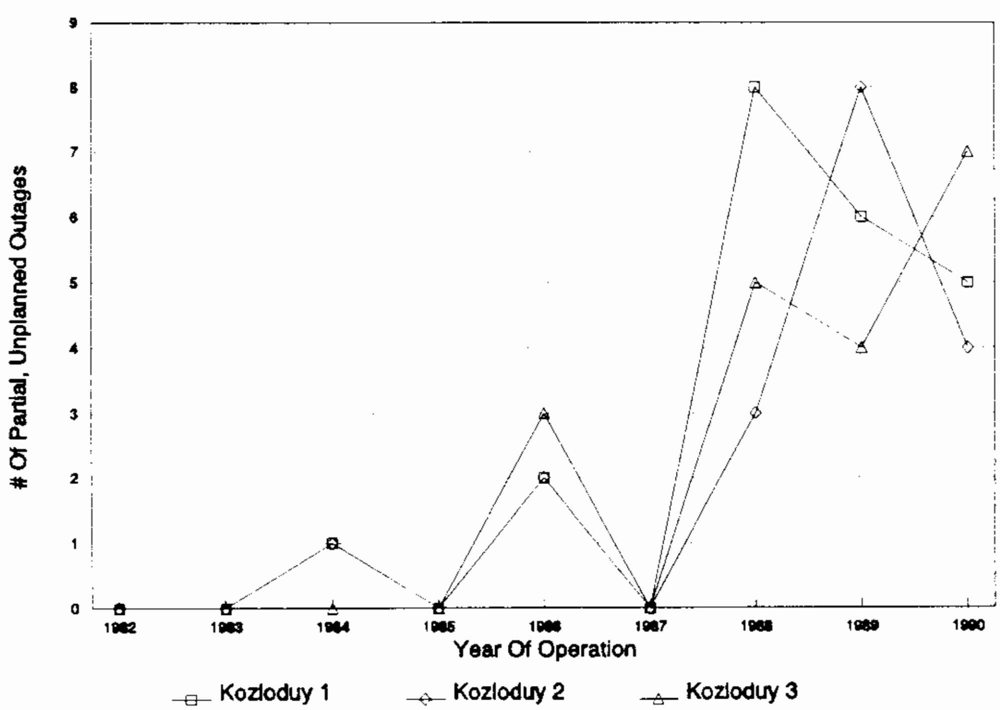

Figure I-13. Kozloduy partial unplanned outages.

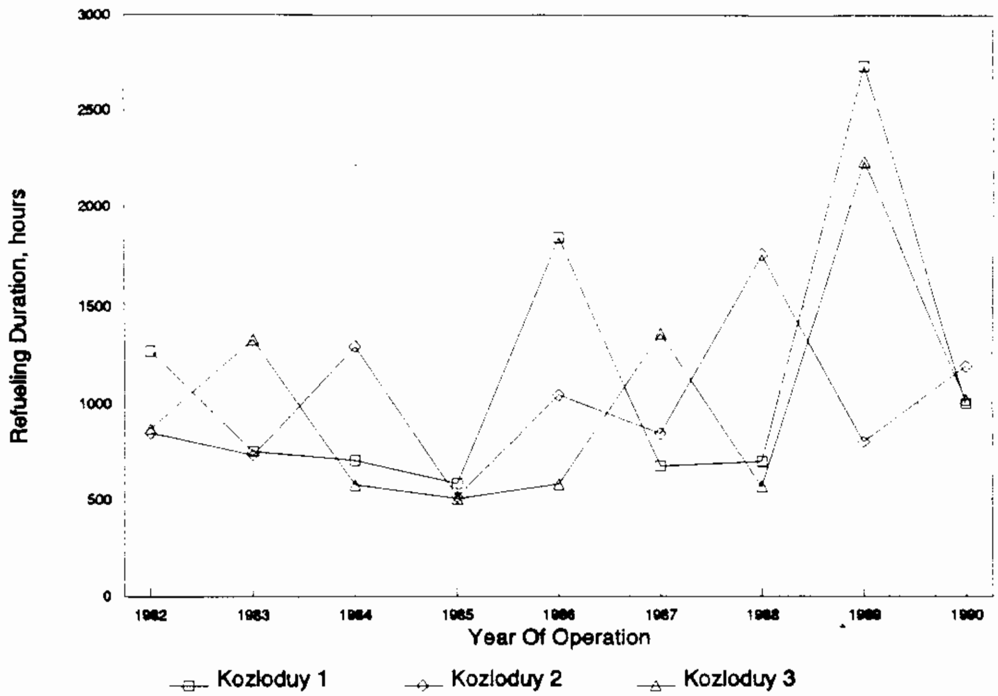

Figure I-14. Kozloduy refueling durations.

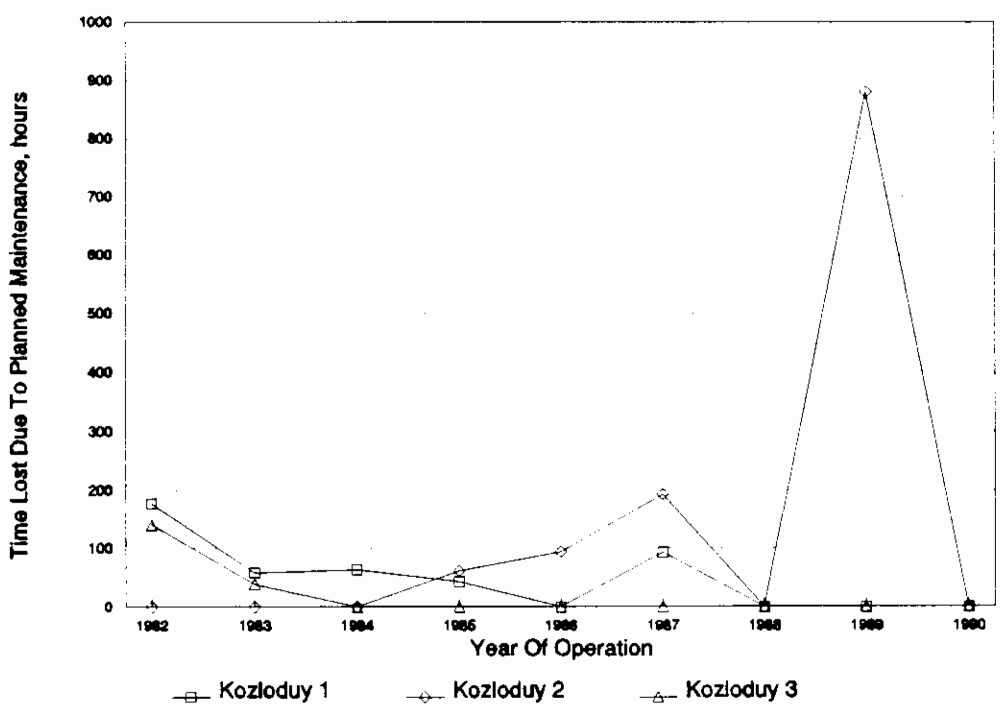

Figure I-15. Kozludoy planned maintenance.

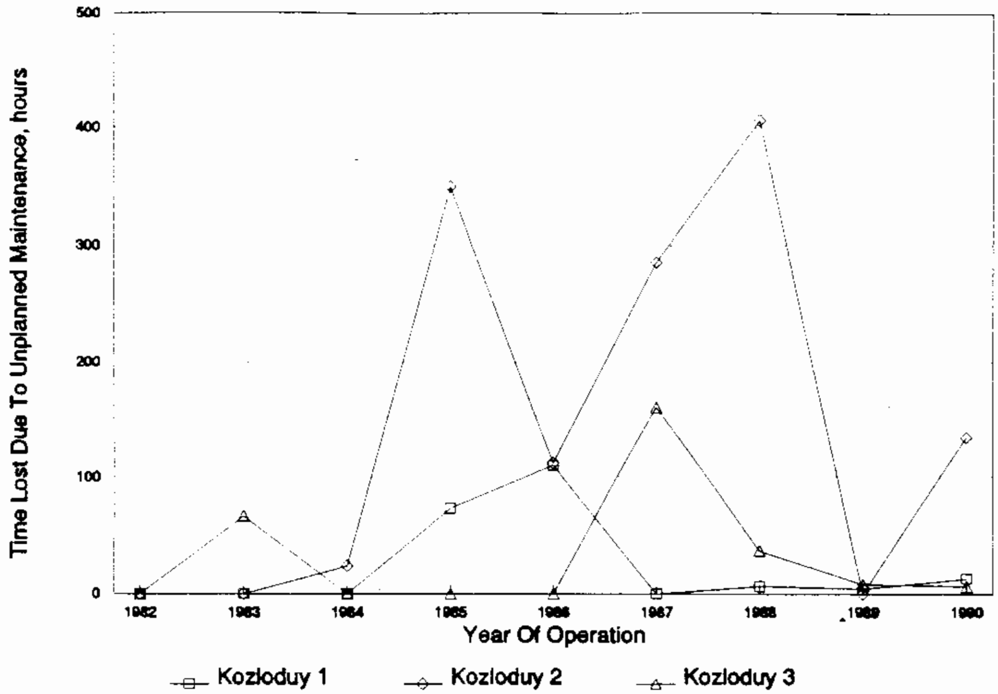

Figure I-16. Kozloduy unplanned maintenance.

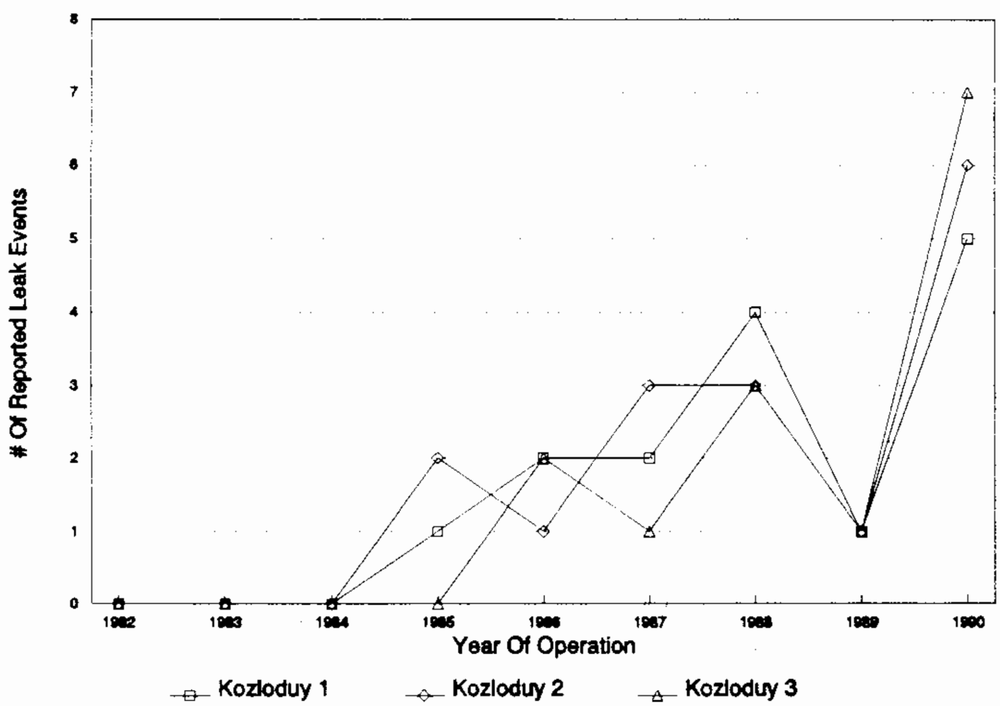

Figure I-17. Kozloduy reported leak events.

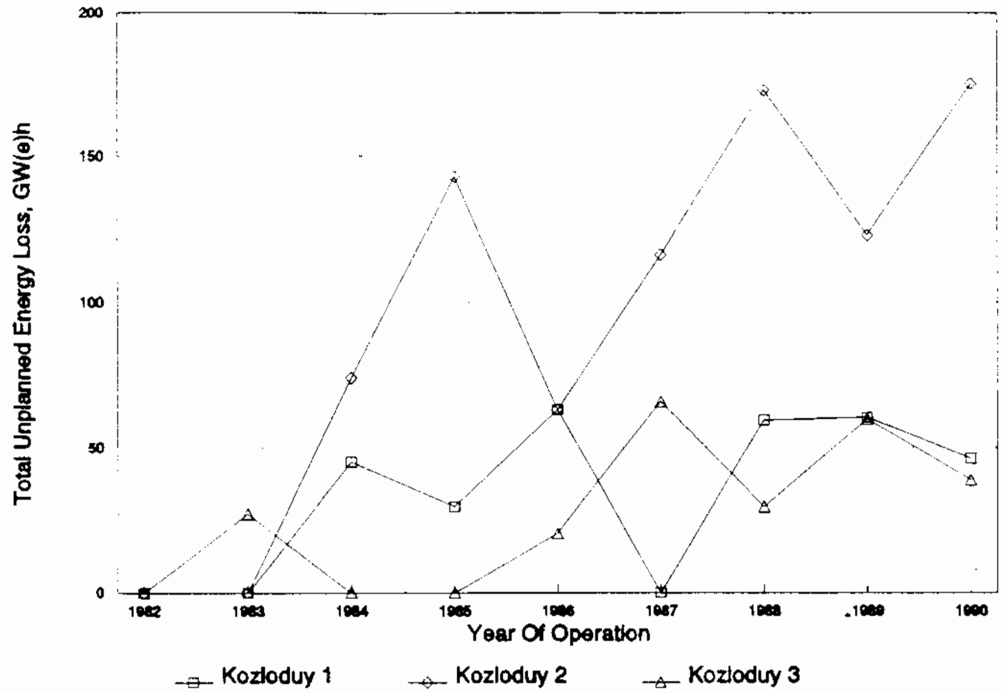

Figure I-18. Kozloduy unplanned energy losses.

Appendix II: Photographs from Bohunice and Kozloduy

Bohunice

Figure 1A - Exterior of the Reactor Building for Unit 1,2
Figure 1B - Crosswalk Between the Reactor Buildings and Service Building
Figure 1C - General Photo of Area Within Site Boundary Showing Cooling Towers

Figure 2A - Main Generator No.1 of Unit 4. Note presence of CO2 fire fighting equipment and Main Generator built by Skoda Works. Material condition of balance of plant insulation was found to be excellent.

Figure 2B - Closeup of Main Generator. Note cleanliness (shine on all metal surfaces) and presence of security guard throughout tour.

Figure 3A - Interior of Reactor Building showing laydown areas and fuel handling machines.

Figure 3B - Closure of Confinement Vessel.

Figure 4A - Control Room of Bohunice Unit 1 (VVER-440 Model 230).Note the swinging doors which lead to the Turbine Hall (Steam line rupture in the turbine hall would lead to loss of control room). Operators wear blue coveralls. Layout of the control room is similar to US plants.

Figure 4B - Wide angle shot of the Bohunice Unit 1 control room. Note the linoleum type permanent flooring.

Figure 4C - Wide angle shot of the Bohunice Unit 4 (VVER-440 Model 213) control room. Note the very large increase in the amount of instrumentation and display devices. Mimic boards now reach to the ceiling. Also observable are CRT displays. Control room flooring uses drop panels typical of modern US plant control rooms.

Kozloduy

Figure 5A - Main entrance point to Kozloduy Units 1-4.

Figure 5B - Closeup shot of old Administration building. Note the missing or broken windows.

Figure 5C - Radwaste processing building associated with Unit 1. Note the missing, broken, and boarded up windows.

Figure 5D - Leakage of liquid radwaste from structural cracks in the crossover tunnel between Unit 1 and the radwaste processing building. We were told the source of the water was a 600 gal/day spent fuel storage pool leak that has flooded Unit 1. The liquid trickling down from the cracks reads at six to eight times background radiation.

Figure 6A - Emergency Condensate Storage Tank from Unit 4. Note that the sheet metal over the fibrous insulation has fallen off and the underlying insulation is saturated with rainwater. This raises major questions regarding freeze protection for this tank in winter time.

Figure 6B - No. 2 Generator for Unit 4. The plant uses Russian designed and manufactured steam turbines. The insulation appears "beaten up" and covered with oil drippings.

Figure 6C - Moisture separator reheater piping and the entrance to the Unit 4 control room (via swinging glass doors). Also visible from the photo are the uneven flooring sections on the turbine decking.

Figure 7A - Unit 4 control room entrance from the turbine hall. An example of operator aids for heat and cooldown are shown on the wall. Note also the marble tiled floors and wooden paneling surrounding the backs of the control panels.

Figure 7B - Shift Supervisor at the main control boards. Note the use of plastic cubes over switches to prevent inadvertent operation and the operator aids posted just in front of the shift supervisor.

Figure 7C - Wide angle photo of the main control boards.